PATENT SPECIFICATION (11) 1 593 446

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(21) Application No. 23466/78 (22) Filed 26 May 1978
(31) Convention Application Nos. 807 413 and 807 414
(32) Filed 17 June 1977 in
(33) United States of America (US)
(44) Complete Specification published 15 July 1981
(51) INT CL³ F04C 2/02, 15/00
(52) Index at acceptance F1F 1A7 AX D EW EY

(19)

(54) ORBITING SCROLL-TYPE LIQUID PUMP AND SCROLL MEMBERS THEREFOR

(71) We, ARTHUR D. LITTLE, INC., a corporation organized and existing under the laws of the Commonwealth of Massachusetts, of 25, Acorn Park, Cambridge, Massachusetts 02140, United States of America, do hereby declare the invention, for which we pray that a patent may be granted to us, and the method by which it is to be performed, to be particularly described in and by the following statement:—

This invention relates to orbiting scroll-type liquid pumps and scroll members therefor, and such liquid pumps which may be immersed in the liquid being pumped.

There is known in the art a class of devices generally referred to as "scroll" pumps, compressors and engines wherein two interfitting spiroidal or involute spiral elements of like pitch are mounted on separate end plates. These spiral elements are angularly and radially offset to contact one another along at least one pair of line contacts such as between spiral curved surfaces. A pair of line contacts will lie approximately upon one radius drawn outwardly from the central region of the scrolls to form one or more fluid volumes or pockets. The angular position of these pockets varies with relative orbiting of the spiral centers; and all pockets maintain the same relative angular position. As the contact lines shift along the scroll surfaces, the pockets thus formed experience a change in volume. In compressors and expansion engines there are thus created zones of lowest and highest pressures which are connected to fluid ports. In liquid pumps the volume ratio remains unity throughout. The outermost and innermost pockets are connected to liquid ports, and the flow of liquid may be either outwardly from the innermost pocket or inwardly from the outermost pocket.

Although, when compared with expanders and compressors, orbiting scroll liquid pumps offer many advantages, including less serious leakage problems and lower operating temperatures, these advantages cannot be realized in practice in the form of commercially acceptable devices until such scroll liquid pumps can be made to operate at reasonable speeds (e.g., at least 1800 rpm) in an essentially pulsation-free manner. The scroll liquid pumps of this invention incorporates the means for either eliminating pressure pulses or for reducing such pressure pulses below that level where such pulses will adversely affect the performance and efficiency of the pumps. As will be apparent from the discussion presented below in conjunction with the scroll pump embodiment illustrated in Figs. 62—84, scroll liquid pumps offer the possibility of being constructed to be immersed in the liquid which is being pumped, and particularly in the fuel tanks of self-propelled vehicles, e.g. automobiles.

It is therefore a primary object to provide unique stationary and orbiting scroll members which when incorporated in a scroll liquid pump, make it possible to operate the pump quietly and at reasonably high speeds with high efficiency to deliver a flow of liquid free from pulsations.

According to one aspect of this invention there are provided mating scroll members suitable for incorporation in an orbiting scroll-type liquid pump, comprising in combination a stationary scroll member which when *in situ* is motionless, having a central liquid port and comprising a stationary end plate, a stationary involute wrap of one and one-half involute turns affixed to one surface of the stationary end plate, and stationary liquid transfer passage means in the form of a recess cut in the one surface of the stationary end plate; and an orbiting scroll member which when *in situ* is orbited with respect to the stationary scroll member by driving means, comprising an orbiting end plate, an orbiting involute wrap of one and one-half involute turns affixed to one surface of the orbiting end plate, and orbiting liquid transfer passage means in the form of a recess cut in said one surface of the orbiting end plate; the stationary and orbiting recessed liquid transfer passage means being located and configured to permit fluid flow

therethrough substantially immediately after the orbiting involute wrap has reached that point in its orbiting cycle when the scroll members define three essentially sealed-off liquid pockets.

According to another aspect of this invention there is provided an orbiting scroll-type liquid pump, comprising in combination the mating scroll members hereinbefore defined; axial force applying means arranged to urge the scroll members into axial contact; coupling means to maintain the scroll members in fixed angular relationship; liquid inlet means and liquid discharge means; and driving means for orbiting the orbiting scroll member whereby the side flanks along with the end plates of the involute wraps define moving liquid pockets of variable volume, a peripheral volume around the pockets and a discharge zone.

According to a feature of this invention there is the liquid pump as herein defined which is suitable for immersion in the liquid to be pumped; which includes housing means defining a chamber containing the scroll members therein and having the liquid inlet means on one end thereof and the liquid discharge means on the other end thereof; and which is further characterized in that the driving means include motor means located within the housing chamber between the scroll members and the other end of the housing, whereby liquid pumped radially outward by the scroll members and through the pump flows around the driving means and maintains a predetermined hydraulic pressure within the chamber to provide the axial force applying means.

In order that the present invention may be more readily understood, an embodiment thereof will now be described by way of example and with reference to the accompanying drawings in which

Figs. 1 and 2 are top plan and cross sectional views of one embodiment of a stationary scroll element constructed in accordance with this invention and being particularly suited for use in a scroll liquid pump in which the liquid flow is inwardly directed;

Figs. 3 and 4 are top plan and cross sectional views of an orbiting scroll element for use with the stationary scroll element of Figs. 1 and 2;

Figs. 5—20 are alternating transverse and longitudinal cross sections of the stationary and orbiting scroll elements of the embodiment of Figs. 1—4 illustrating the operation of the centrally located discharge porting of that embodiment;

Figs. 21 and 22 are top plan and cross sectional views of another embodiment of a stationary scroll element constructed in accordance with this invention and being particularly suited for use in a scroll liquid pump in which the liquid flow is outwardly directed;

Figs. 23 and 24 are top plan and cross sectional views of an orbiting scroll element for use with the stationary scroll element of Figs. 21 and 22;

Figs. 25—40 are alternating transverse and longitudinal cross sections of the stationary and orbiting scroll elements of the embodiment of Figs. 21—24 illustrating the operation of the peripherally located discharge porting of that embodiment;

Figs. 41 and 42 are top plan and cross sectional views of yet another embodiment of a stationary scroll element constructed in accordance with this invention incorporating both central and peripheral discharge porting and in which the liquid flow may be either inwardly or outwardly directed;

Figs. 43 and 44 are top plan and cross sectional views of an orbiting scroll element for use with the stationary scroll element of Figs. 41 and 42;

Figs. 45—60 are alternating transverse and longitudinal cross sections of the stationary and orbiting scroll elements of the embodiment of Figs. 41—44 illustrating the operation of the discharge porting of that embodiment when the liquid flow is inwardly or outwardly directed;

Fig. 61 is a longitudinal cross section of a scroll liquid pump constructed in accordance with this invention;

Fig. 62 is an enlarged longitudinal cross section of a scroll liquid pump constructed in accordance with this invention and which is particularly suited as a fuel pump for an automobile wherein the pump is immersed in the fuel;

Fig. 63 is a plan view of the discharge end of the pump of Fig. 62;

Fig. 64 is a partial longitudinal cross section of a modification of the pump of Fig. 62 illustrating an alternate means of providing electrical connections with the motor and of providing a secondary counterweight;

Fig. 65 is a plan view of the discharge end of the pump of Fig. 64;

Fig. 66 is an enlarged longitudinal cross section of the inlet end of an embodiment of a scroll-type liquid pump of this invention illustrating in detail the driving and coupling means, the scroll members, the porting system and the axial load carrying means;

Fig. 67 is a cross sectional view of the pump of Fig. 66 taken transverse to the machine axis through plane 67—67 of Fig. 66;

Fig. 68 is a cross sectional view of the pump of Fig. 66 taken transverse to the machine axis through plane 68—68 of Fig. 66;

Figs. 69, 70 and 71 illustrate three embodiments of the axial load carrying means of the pump of Fig. 66 (in addition to the embodiment illustrated in that figure) used in conjunction with a separate coupling member;

Fig. 72 illustrates one embodiment of an axial load carrying means and a coupling member combined in one apparatus component;

Fig. 73 is a cross section of the apparatus

of Fig. 72 taken through plane 73—73 of Fig. 72 and illustrating the respective positioning of the ball thrust bearings used;

Fig. 74 presents details in diagrammatic plan and cross sectional views of the factors involved in the use of the ball thrust bearings of Fig. 73 and 74;

Fig. 75 illustrates another embodiment of an axial load carrying means and coupling member combined in one apparatus component;

Figs. 76 and 77 are plane and cross sectional views, respectively, of the axial load carrying/coupling means used in Fig. 74;

Fig. 78 illustrates yet another embodiment of a combined axial load carrying/coupling means in which spherical members serve in the dual function of load carrying and coupling;

Figs. 79 and 80 are plane and cross sectional views, respectively, of the axial load carrying/coupling means of Fig. 78;

Fig. 81 illustrates a modification of the axial load carrying/coupling means of Fig. 78 in which rollers serve in the dual function of load carrying and coupling;

Figs. 82 and 83 are plane and cross sectional views, respectively, of the axial load carrying/coupling means of Fig. 81; and

Fig. 84 is a cross sectional view of a tank containing liquid in which the pump of this invention is immersed.

The sealed pocket of fluid within the scroll apparatus is bounded by two parallel planes defined by end plates, and by two cylindrical surfaces defined by the involute of a circle or other suitably curved configuration. The scroll members have parallel axes since in only this way can the continuous sealing contact between the plane surface of the scroll members be maintained. A sealed pocket moves between these parallel planes as the two lines of contact between the cylindrical surfaces move. The lines of contact move because one cylindrical element, e.g., a scroll member, orbits within the other. This is accomplished by maintaining one scroll member stationary and orbiting the other scroll member. Pumping is achieved by this mechanism in the pump of this invention and hence the pump is referred to as an orbiting scroll-type liquid pump.

Throughout the following description the term "scroll element" will be used to designate the basic component which is comprised of an end plate having the unique porting of this invention and the involute-shaped component which defines the contacting surfaces making movable line contacts. The term "wrap" will be used to designate the involute component making moving line contacts. These wraps have a configuration, e.g., an involute of a circle (involute spiral) or an arc of a circle, and they have both height and thickness. Finally, the term "scroll member" will be applied to the entire stationary or orbiting component of which the stationary or orbiting scroll element is a part.

In the case of scroll apparatus used as compressors and expanders, the wraps of the scroll members may comprise any desired number of turns of an involute. However, a scroll liquid pump must be constructed so that each of the scroll members has a wrap of one and one-half turns of an involute. This requirement is dictated by the requirement that a scroll device designed to pump a liquid must have a compression ratio of exactly one. If the scroll apparatus has a compression ratio greater than one, it would attempt to compress the trapped liquid. Since liquids are essentially incompressible, any scroll pump operating with a compression ratio greater than one would jam and malfunction. Thus, in order for a scroll pump to have a compression ratio of one the members must have no more than one and one-half wraps of involute. This length of wrap achieves the desired continuity of seal between the peripheral zone and interior zone defined between the scroll members without compressing any of the trapped fluid.

However, the limiting of the wraps to one and one-half involute turns is not the total solution to constructing an efficient, practical scroll liquid pump, for this does not solve the serious problem of pressure pulsations developed during the discharge of liquid from the pump. These pressure pulsations develop because the rate of change in the volume of the scroll pocket (whether centrally or peripherally located) which is in communication with the discharge port is greater than the rate of change in discharge area opening for that pocket. Therefore, driving the orbiting scroll member forward compresses the liquid in the discharging pocket, forces it through a narrow discharge gap, and thus develops an intermittent high-pressure pulse. Such pressure can be so great that it can damage the hardware forming the scroll members.

In small, relatively inefficient pumps operating at relatively slow speeds, it may be possible to tolerate some pressure pulsation; but in most applications for a liquid pump it should be capable of relatively pulsation-free delivery flow and of operating at reasonable speeds, e.g., 1800 rpm or greater.

The scroll pump being described achieves pulsation-free liquid pumping at relatively high flow rates through a novel porting arrangement. This porting relieves the pressure in the discharging pocket which gives rise to pulsations by providing a much more rapid opening of the discharge port than when the movement of the orbiting scroll member wrap is relied on solely to open it.

Since the liquid flow through a scroll pump may be from the peripheral zone inwardly to the central pocket or from the central pocket outwardly to the peripheral zone, the novel

porting arrangement may be associated with the central pocket, the peripheral volume or both.

Figs. 1—4 illustrate stationary and orbiting scroll elements suitable for incorporation into scroll members to form a scroll pump in which liquid flow is from the peripheral volume inwardly to the center pocket. The stationary scroll element 10 of Fig. 1 is comprised of an end plate 11 and an involute wrap 12 integral with or mounted on a separate member on the inner surface 13 of end plate 11 (see for example U.S. Patent 3,994,635). Involute wrap 12 begins at a line of contact 14 which is drawn as a tangent to the involute generating radius and through the points of contact between the involutes of the fixed and orbiting scroll members, and it ends at a line of contact 15 which is also drawn as a tangent to the involute generating radius. Thus this wrap is formed of one and one-half turns of the involute; and it has an outer flank surface 16, an inner flank surface 17 and an end surface 18.

End plate 11 has a central boss 20 extending from outer surface 21. This boss 20 has an annular groove 22 arranged to hold a sealing ring when the stationary scroll element is assembled in a stationary scroll member in a liquid pump as shown in Fig. 61. A liquid port 23 extends through end plate 11 and boss 20 and a recessed transfer passage 24 is cut in surface 13 to provide liquid communication with port 23. Together port 23 and recessed transfer passage 24 form a manifold means or discharge zone. As shown in the top plan view of Fig. 1, transfer passage 24 has one principal boundary 25 coinciding with a line which passes through the center 26 of end plate 11 and is parallel to lines of contact 14 and 15 and another principal curved boundary 27 which conforms in configuration to the outer surface 34 of the involute wrap 32 of the orbiting scroll element 30 (Figs. 3 and 4) when the two scroll elements are oriented such that the maximum of four contact points between the flanks of the wraps is achieved as shown in the orientation of the wraps in Fig. 5. Thus curved boundary 27 may be defined as a partial tracing of an involute wrap edge of the mating scroll elements. These principal boundaries are joined through blending radii 28. Although transfer passage 24 may be semicircular rather than having an involute boundary 27, the involute configuration illustrated is preferred for more accurate porting. Inasmuch as recessed transfer passage 24 is located within the involute wrap, it may, for convenience, be termed as "inner passage."

Although port 23 is shown in Figs. 1 and 2 in a position to intersect boundary 25 of transfer passage 24, it is also within the scope of this invention to position port 23 anywhere within the innermost pocket formed by the wraps of the scroll elements, so long as port 23 is in communication with transfer passage 24 and does not interfere with the integrity of wrap 12.

As will be seen in Figs. 3 and 4, the orbiting scroll element 30 has a configuration similar to that of the stationary scroll element 10. The orbiting scroll element 30 is formed of an end plate 31 and an involute wrap 32 affixed to or integral with the inner surface 33 of end plate 31. Wrap 32 has an outer contacting flank surface 34, and inner flank surface 35 and an end contacting surface 36. Involute wrap 32 begins at a line of contact 37 which is drawn as a tangent to the involute generating radius and through the points of contact between the involutes of the stationary and orbiting scroll elements, and it ends at a line of contact 38 which is also drawn as a tangent to the involute generating radius. A recessed transfer passage 39 is cut into the surface 33 of the end plate of the orbiting scroll element, its location and configuration bearing the same relationship to the stationary scroll element as transfer passage 24 of the stationary element bears to the orbiting scroll element. That is, transfer passage 39 is defined by one principal straightline boundary 40 coinciding with a line drawn through end plate center 41 and parallel to lines of contact 37 and 38 and another principal curved boundary 42 corresponding to a partial tracing of outer surface edge 16 of wrap 12 of the stationary scroll element when the scroll elements are oriented to achieve the maximum of four points of contact as shown in Fig. 5. These principal boundaries are likewise joined through blending radii 43. In combination these recessed transfer passages 24 and 39 in the end plates of the scroll elements comprise one embodiment of the unique porting system of the apparatus of this invention.

If the scroll elements are manufactured from a metal such as stainless steel, the recessed transfer passages may be formed by machining them out; and if they are formed of a synthetic resin such as a polyimide, the recessed transfer passages may be formed during the molding of the elements. In general, it will be preferable to form these recessed passages to have a depth approximately equal to the width of the involute wrap.

The manner by which the porting system of the scroll elements of Figs. 1—4 achieves essentially pulsation-free liquid pumping may be detailed with reference to Figs. 5—20 which illustrate the operation of a scroll pump using these scroll members and pumping a liquid flowing radially inward. Figs. 5—20 illustrate various positions at one-eighth orbit intervals of the scroll elements during one pumping cycle, the odd-numbered figures being cross sections of the wraps taken transverse to the center line of the apparatus and the even-numbered figures following them being the corresponding longitudinal cross sections through the wraps.

Like reference numerals in Figs. 5—20 are used to refer to like components of Figs. 1—4. Although it would not be normal to see the outline of the recessed transfer passage 39 of the orbiting scroll element in those cross sectional drawings taken transverse to the center line (e.g., Figs. 5, 7, etc.) these outlines have been dotted in to provide the location of the transverse passages in the accompanying longitudinal cross sections (e.g., Figs. 6, 8, etc.). Boss 20 of the stationary scroll element has been eliminated in the longitudinal cross sections of Figs. 6, 8, etc. for the sake of simplicity.

In the operation of the scroll pump, the orbiting scroll element 30, mounted in an orbiting scroll member, is driven to orbit (by means described in detail with reference to Fig. 61) the stationary scroll element 10 mounted in a stationary scroll member, the flank surfaces 16 and 17 and 34 and 35 of the stationary and orbiting scroll elements making moving line contacts. As will be described in connection with the description of Fig. 61, there can, in actual practice, be a very small clearance, e.g., from about 0.001 to about 0.005 inch, between the flank surfaces of the involutes. The end surfaces 18 and 36 of the stationary and orbiting scroll elements in making contact with the inner surfaces 33 and 13 of the orbiting and stationary scroll elements, respectively, define the moving pockets 50, 51 and 52, the volumes of which and liquid communication between which change to effect the movement of the liquid through the pump. Because liquids have much higher viscosities than gases and because the volume ratio within the liquid pump is one rather than greater than one, the need for efficient radial sealing across the contacting end surfaces 18 and 36 of the wraps from pocket to pocket is not as stringent as for compressors or expanders. It is therefore unnecessary to provide radial sealing means such as those described in U.S. Patent 3,944,636.

The somewhat simplified longitudinal cross section of Fig. 6 shows the stationary scroll element 10 mounted in a scroll member which includes a housing plate 53 having an annular extension 54, the end surface 55 of which serves as a contacting surface with which the inner surface 56 of the orbiting scroll member 57, of which orbiting scroll end plate 31 is a part, makes moving contact to define a peripheral volume 58 into which the liquid to be pumped is introduced through peripheral port 59. Fig. 61 illustrates the incorporation of the scroll members in a complete scroll pump in more precise detail. In the remaining even-numbered figures 8, 10 .... 20, only those portions of the scroll elements including the wraps and porting will be illustrated, it being understood that each has a peripheral volume.

It is assumed that the cycle to be described begins with the sealing off of center pocket 52 at which point pockets 50 and 51 are also sealed off. Liquid is discharged through the discharge manifold means comprising port 23 and transfer passage 24. In this mode of operation central pocket 52 serves as a discharge zone. As shown in Figs. 5 and 6, pockets 50 and 51 are at their maximum volumes and essentially completely sealed off from central pocket 52, discounting any small clearances between wrap flanks and between wrap end surfaces and end plates. Assume first that neither of the recessed transfer passages 24 nor 39 is cut in the end plates. The effect of this may be seen in Figs. 7 and 8 which show the wrap positions after the completion of one-eighth of a total orbit of the orbiting scroll member, the orbit direction of which is shown by the dotted arrow. The volumes of pockets 50, 51 and 52 begin to decrease; and, since the liquid in the pump is essentially noncompressible, it is forced under pressure from pockets 50 and 51 into center pocket 52 through the relative narrow passages 60 and 61 created by wrap movement. Moreover, the comparative sizes of central pocket 52 and discharge port 23 are such as to accentuate this effect. The result is the building up of pressures within the system which have a serious adverse affect upon the scroll hardware and the generation of severe pressure pulses giving rise to inefficient and noisy operation.

The presence of inner recessed transfer passages 24 and 39 in the fixed and orbiting scroll members, respectively, essentially eliminates this undesirable situation. As will be seen from Fig. 8, these transfer passages are so contoured and located as to open essentially instantaneously after the closing of pocket 52. Thus these transfer passages 24 and 39 which were previously blocked off by virtue of the position of the wrap, are opened with the continued movement of the orbiting wrap. Transfer passages 24 and 39 are of a size and depth to augment passages 60 and 61 to the extent that there is sufficient flow capacity to prevent the buildup of pressure within the pockets and to permit nonpulsating flow of the liquid through port 23. (In the drawings the flow of liquid is indicated by the solid arrows).

As will be seen in Figs. 9—14, transfer passages 24 and 39 remain open to permit essentially nonpulsating liquid flow from pockets 50 and 51 into 52; and then, as pockets 50, 51 and 52 decrease in volume and become virtually one central pocket, these passages continue to permit the smooth discharge through the discharge port 23. As the combined volume of pockets 50, 51 and 52 decreases liquid from peripheral volume 58 begins to enter into what may be termed "open" pockets 65 and 66 defined between the scroll wraps. These pockets 65 and 66 are open in the sense that

they are in direct communication with peripheral volume 58. As will be seen in Figs. 9 and 10, as the orbiting progresses through its first quarter, the passages 60 and 61 formed by wrap movement grows larger and transfer passages 24 and 39 are full open allowing free flow of liquid into center pocket 52 and through the discharge manifold means. Passages 60 and 61 continue to be enlarged until one-half orbit is completed as seen in Figs. 11—14. Although transfer passages 24 and 39 continue to provide communication among pockets 50, 51, 52, they no longer are required to conduct an appreciable amount of liquid and they are gradually closed by the movement of the orbiting scroll member. As will be seen in Figs. 15—20, the situation obtains until the center pocket 52 can be considered to be a separate pocket at completion of about three-quarters of the orbit and the "open" pockets 65 and 66 are sufficiently closed off from peripheral volume 58 to be considered to have formed new outer pockets 50 and 51, open to the peripheral volume from ever decreasing passages 67 and 68.

With the closing of passages 67 and 68 all of the closed pockets including central pocket 52 reach maximum liquid volume to set up the situation depicted in Figs. 5 and 6 and begin the cycle anew. So long as passages 67 and 68 are open to the peripheral volume, the transfer passages 24 and 39 are closed; but, as noted above, essentially instantaneously with the closing of the three pockets, the porting system of this invention becomes operative.

Figs. 21—24 illustrate stationary and orbiting scroll elements incorporating the porting system of this invention and suitable for incorporation into a scroll pump in which liquid flow is from the central pocket radially outward to the peripheral volume. The fixed scroll element 70 of Fig. 21 is comprised of an end plate 71 and an involute wrap 72 integral with or affixed to inner surface 73. Wrap 72, like wrap 12 of Figs. 1 and 2, begins at a line of contact 74 and ends at a line of contact 75 and constitutes an involute of one and one-half turns. Wrap 72 has an outer flank surface 76, an inner flank surface 77 and an end surface 78. End plate 71 has a central boss 79 on outer surface 80. A liquid port 81 extends through end plate 71 and boss 79.

A recessed transfer passage 85 is cut in inner surface 73 of end plate 71. As shown in the top plan view of Fig. 21, transfer passage 85 has a principal inner boundary 86 conforming in configuration to the inner surface 95 of the involute wrap 92 of the orbiting scroll member 90 (Figs. 23 and 24) when the two scroll members are oriented such that the maximum of four contact points between the flanks of the wraps is achieved as shown in Fig. 25. Thus this principle boundary 86, like boundary 27 of inner passages 24 of Fig. 1, represents a partial tracing of an involute wrap edge of the mating scroll element. The second principal or outer boundary 87 of transfer passage 85 is cut to follow the contour of inner boundary 86 and is spaced radially outward therefrom. Boundaries 86 and 87 are joined through blending radii 88. The distance between boundaries 86 and 87 is preferably about twice the thickness of the involute wrap of the scroll element. Transfer passage 85 is thus an arcuate recess contiguous with or spaced a short distance from the outer end of wrap 72 and extending through an arc ranging between about 45 and 90 degrees. Since transfer passage 85 is located outside the involute wrap it may, for convenience, be referred to as an "outer" passage.

The orbiting scroll element 90, shown in top plan and cross sectional views in Figs. 23 and 24, is formed of an end plate 91 and an involute wrap 92 integral with or affixed to inner surface 93. Wrap 92 begins at line of contact 74 and ends at line of contact 75, being formed as one and one-half turns of the involute. Wrap 92 has an outer contacting flank surface 94, an inner flank surface 95 and an end contacting surface 96. A recessed transfer passage 97, corresponding to transfer passage 85 of the stationary scroll element, is cut in inner surface 93 of end plate 91. As shown in the top plan view of Fig. 23, transfer passage 97 has a principal inner boundary 98 conforming in configuration to a partial tracing of the inner surface edge 77 of involute wrap 71 of the stationary scroll element 70 when the two scroll elements are oriented such that the maximum of four contact points between the flanks of the wraps is achieved. The principal outer boundary 99 of transfer passage 97 has the same contour as the principal inner boundary 98 and the passage is closed by blending radii 100. It is configured and sized to correspond to the arcuate recessed transfer passage 85 of the stationary scroll member.

The manner in which the porting system of the scroll elements of Figs. 21—24 achieve essentially pulsation-free liquid pumping may be detailed with reference to Figs. 25—40 in which the scroll elements are shown pumping a liquid radially outward. As in the case of Figs. 5—20, Figs. 25—40 illustrate various positions of the scroll elements during one pumping cycle, the odd-numbered figures being cross sections of the wraps taken transverse to the center line of the apparatus and the even-numbered figures following them being the corresponding longitudinal cross sections through the wraps. In Figs. 25—40 the longitudinal plane through the scroll members is rotated about the center line from figure-to-figure to intersect the recessed transfer passages 85 and 97 to best illustrate their opening and closing.

Scroll elements 70 and 90 are shown in Figs. 26 to be incorporated in a scroll pump in the same manner as shown in Fig. 6. Thus

the stationary scroll element 70 is mounted in a housing plate 105 which has an annular extension member 106 providing a contacting surface 107 for the inner surface 93 of orbiting scroll member extension 108. A peripheral liquid volume 110 is defined within the enclosed volume thus created and a port 109 (of which there may be more than one) is cut through housing plate 105 to provide liquid communication between peripheral volume 110 and a liquid reservoir, not shown. In the operation to be described, port 109 serves as the liquid discharge manifold for the peripheral discharge zone thus created, the liquid flow being radially outward. Port 81 in the fixed scroll member is therefore the inlet manifold. In the wrap positions illustrated in Figs. 25 and 26 there are two closed outer pockets 111 and 112 and a central pocket 113.

The operation of the porting system is illustrated in detail in Figs. 25—40. It will be assumed that the cycle begins with that point when each of the pockets 111, 112 and 113 has just been sealed off from the others and is at its minimum volume just prior to beginning to enlarge. As in the case of the porting system described above, in Figs. 1—20, there can be a small clearance, e.g. from between about 0.001 and 0.005 inch between the wrap flanks at all times to avoid flank wear. Again, assuming first that there were no arcuate recessed transfer passages in end plates 71 and 91, it will be seen that the liquid in pockets 111 and 112 would be subjected to constantly increasing pressure as the orbiting scroll is driven in the direction indicated by the broken arrows in Figs. 25 and 26. This is due to the fact that the openings 115 and 116 (Fig. 27), created by the movement of the orbiting scroll wrap 92 relative to the stationary scroll wrap 72 are not large enough to permit the flow of the liquid from pockets 111 and 112 into peripheral zone 110 at a rate to prevent excessive pressurization of the liquid in pockets 111 and 112. The result is the development of pressure pulsations and eventual damage to the scroll hardware.

When, however, recessed transfer passages 85 and 97 are present, there are provided, essentially instantaneously after the closing of pockets 111, 112 and 113, additional liquid flow passages. Thus transfer passages 85 and 97 augment passages 115 and 116 created by the movement of the orbiting scroll wrap relative to the stationary scroll wrap and eliminate undue pressurization of the liquid which in turn gives rise to pressure pulsations.

As will be seen from Figs. 27—32, the transfer passages 85 and 97 are closed by the time the orbiting scroll member has completed three-eighths of its orbit, for by this time they are no longer needed to augment liquid passages 115 and 116 which have reached near maximum. Central pocket 113, of course, encompasses more and more of the volume previously part of pockets 111 and 112, a fact that effects sufficient control of the liquid pressure within central pocket 113 as additional liquid is taken in. It will be appreciated from the drawings that as the cycle proceeds, the pockets as numbered and designated in Figs. 25 and 26 become less and less sharply defined, a portion of each of pockets 111 and 112 becoming indistinguishable from central pocket 113. However, for clarity, the reference numerals of Figs. 25 and 26 are used throughout Figs. 27—40 and the description of these drawings.

Passages 115 and 116 between the wraps 72 and 92 remain at their essentially maximum dimension as the pumping continues through three-fourths of the cycle as shown in Figs. 35 and 36. This permits transfer passages 85 and 97 to remain effectively closed, i.e., inoperative. Finally, through the last quarter of the cycle (Figs. 37—40) the small volume of liquid remaining in pockets 111 and 112 is transferred to peripheral volume 110; and at the end of the cycle passages 115 and 116 are closed. As will be apparent from Figs. 33—40, the transfer passages 85 and 97 remain closed since the porting achieved by the movement of the orbiting wrap relative to the fixed wrap is adequate to obtain pulsation-free liquid flow and discharge. With the completion of the cycle, the pockets 111, 112 and 113 are sealed off as shown in Fig. 25 to be in position to begin another cycle.

From the above description of the working of the liquid porting system of this invention it will be seen that the recessed liquid transfer passage means are located and configured to be opened substantially immediately after the orbiting involute wrap has reached that point in its orbiting cycle to define three essentially completely sealed-off liquid pockets and to remain open at least until the liquid passages defined by the movement of the orbiting wrap and providing liquid communication into the liquid discharge zone (whether central or peripheral) are sufficiently large to prevent any substantial pressure pulsation within the scroll pump.

For many applications, liquid scroll pumps designed to operate with radially outward flow are preferable over those designed for inward flow. In the outward flow pumps the hydraulic pressures within the pump can be used to hold the scroll members together, thus generally achieving a more efficient operation. Moreover, it is possible to have a larger discharge porting means, using multiple ports spaced around the peripheral zone if desired. These factors contribute to even more effective reduction or elimination of flow pulsations with the use of the porting system of this invention.

It is also within the scope of this invention to incorporate both central (inner) and peripheral (outer) recessed transfer passages in the end plates of the scroll elements as

illustrated in Figs. 41—44. The stationary scroll element 120 of Figs. 41 and 42 has an end plate 121 and wrap 122 of one and one-half involute turns as in the case of the scroll elements of Figs. 1 and 2 or Figs. 21 and 22. Scroll element 120 has a central port 123, a centrally located recessed transfer passage 124 of the same configuration as passage 24 of Fig. 1 and a peripherally located recessed transfer passage 125 of the same configuration as passage 85 of Fig. 21. In like manner, the orbiting scroll element 130 of Figs. 43 and 44 has an end plate 131 and wrap 132 of one and one-half involute turns as in the case of the scroll elements of Figs. 3 and 4 or Figs. 23 and 24. Scroll element 130 has a centrally located transfer passage 133 and a peripherally located recessed transfer passage 134 of the same size and configuration as shown in Figs. 3 and 23, respectively.

Figs. 45—60 are the same type of cross sectional drawings as Figs. 25—40, the longitudinal planes along which the even numbered Figs., e.g., 46, 48, etc., are taken being rotated in order to show clearly which transfer passages are open. A liquid scroll pump incorporating the scroll elements of Figs. 41—44 can be used to pump liquid radially inward from the peripheral volume through a central discharge zone or radially outward from the central pocket through a peripheral discharge zone. In Figs. 45—60 the sequence of steps shown illustrates the first of these modes of operation, i.e., radially inward. However, Figs. 45—60, taken in a different sequence can also be used to illustrate the operation of the porting system when pumping in the second or radially outward operating mode as will be described. Therefore, in order to use Figs. 45—60 to illustrate both of these operational modes, the flow of liquid in the first inward flow mode will be indicated by an arrow labelled with an encircled numeral 1 followed by a, b .... h, each letter indicating the ordered sequence of the pumping cycle by increments of one-eighth orbit as shown in the previous drawings. The second outward flow mode will be indicated by an arrow labelled with an encircled numeral 2 followed by a, b .... h, also used to indicate the sequence of the pumping cycle. In this latter case, the figures must be examined out of their numbered order as will be described.

The scroll members of Figs. 41—44 are shown in Fig. 46 to be set in a liquid pump in the same manner as described for Fig. 26 and the same reference numerals are used to identify the same elements. As will be seen in Fig. 45, the cycle may be assumed to begin with outer liquid pockets 135 and 136 and central pocket 137 having just been closed. The following description pertains to the first mode of operation; namely, radially inward liquid flow.

It will be seen from Figs. 45—56, and a comparison of these drawings with Figs. 5—16, that the porting systems in which there are both central and peripheral recessed transfer passages (124, 133, 125 and 134) operates in the same manner as the porting system in which there is only the central transfer passages. That is, in a fluid pump having the stationary and orbiting scroll elements of Figs. 41—44 and operating to pump the liquid radially inward, the central transfer passages 124 and 133 serve to augment the center passages 140 and 141 created by the wrap movement to achieve rapid and pulse-free liquid flow through discharge port 123. The peripheral transfer passages are not required and remain inoperative during the first five-eighths of the pumping cycle, since the peripheral passages 142 and 143 created by wrap movement are adequate to admit liquid into the scrolls. However, during the time the orbiting scroll member moves between five-eighths and three-quarters of its orbit (see Figs. 55—58) the orbiting scroll wrap has moved to open the peripheral transfer passages 125 and 134 to augment the flow of liquid through peripheral passages into the open pockets 144 and 145 which are the precursors for and which develop into pockets 135 and 136. The movement of additional liquid into pockets 144 and 145 results in the attainment of smoother liquid flow into and hence more uniform liquid flow through the scrolls. As will be seen from Figs. 57—60, these peripheral transfer passages 124 and 134 remain open and operative until the end of the cycle at which time pockets 135 and 136 are closed off (Figs. 45 and 46).

In order to follow the operation of the porting system as it functions in the second mode, i.e., pumping liquid radially outward, it is necessary to begin with Figs. 45 and 46 and then follow the figures in reversed pair order from Figs. 59 and 60 back through Figs. 47 and 48. The peripheral transfer passages 125 and 134 augment the peripheral wrap passages 142 and 143 during late liquid discharge (Figs. 59 and 60 and Figs. 57 and 58) as they did in the case shown in Figs. 27—30. During this period of the cycle the center pocket 137 is in essence one with pockets 135 and 136, so communication among these pockets presents no problem. The flow of liquid into the central pocket gradually causes the differentiation among pockets 135, 136 and 137 and the presence of center transfer passages 124 and 133 provides for a smooth flow of liquid into these forming pockets and increases the hydraulic force which acts on the wraps to maintain good moving line contacts between their flanks. This situation continues (Figs. 55 and 56 through Figs 47 and 48); and as the center wrap passages 140 and 141 continue to decrease, the role of the open center transfer passages 124 and 133 becomes more important in insuring a smooth nonpulsating

flow of liquid through inlet port 123 and center pocket 137 into pockets 135 and 136. With the closing of these pockets as shown in Figs. 45 and 46, the scroll wraps have been brought around through another cycle and are in a position to discharge liquid to the peripheral volume 138 with the reopening of peripheral transfer passages 125 and 134.

Although it is possible to operate the scroll members of Figs. 1—4 and of Figs. 21—24 in either the radially inward or radially outward mode, for most applications, and particularly for larger scroll devices running at relatively high speeds, it is preferable to use the scroll members of Figs. 41—44, that is those having both central or inner and peripheral or outer recessed transfer passages.

Fig. 61 is a longitudinal cross section of a scroll liquid pump incorporating the scroll elements and porting system of this invention. The scroll members illustrated are those incorporating the scroll elements of Figs. 42—44 at that point of their pumping cycle shown in Figs. 51 and 52. The same reference numerals used to identify components of the fixed and orbiting scrolls and the pockets defined by them used in Figs. 41—44, 51 and 52 are used in Fig. 61.

The pump of Fig. 61 is comprised of a stationary scroll member 150 formed of a stationary plate 151 in which stationary scroll element 120 is rigidly mounted; and orbiting scroll member 152 formed of an orbiting plate 153 in which orbiting scroll 130 is rigidly mounted, a coupling member 154, a drive mechanism generally indicated by reference numeral 155; crank and shaft assembly means generally indicated by reference numeral 156; housing 157 including an oil sump 158, cooling fan 159 and cover 160.

Stationary plate 151 of the stationary scroll member terminates in a peripheral ring 165 and an outwardly extending flange 166, these portions of plate 151 forming a part of the apparatus housing. Stationary plate 151 also has a central stub extension 167 defining a liquid passage 168 in direct communication with central port 123 of the stationary scroll, these making up a liquid conduit means which may serve as a liquid inlet or discharge conduit depending upon the mode of operation chosen. Boss 79 of stationary scroll 120 extends into extension 167 and is sealed therein through o-ring 169. Central stub extension 167 is internally threaded at 170 for engagement with a liquid conduit (not shown). Stationary plate 151 also has one or more peripherally positioned stub extensions 175 each of which defines a liquid inlet or discharge conduit means 176 communicating with the peripheral zone 138 and being threaded at 177 for engagement with a liquid conduit (not shown).

The diameter of orbiting plate 153 of the orbiting scroll member is sufficiently great such that it always extends beyond the inner edge of flange 166, thus permitting, if desired, the placement of an oil seal ring 180 between plate 153 and flange 166 to seal off the scroll pockets from the remainder of the apparatus. This in turn allows the drive mechanism and bearings to be oil-lubricated while maintaining the working fluid substantially free from any liquid. In those applications where the liquid being pumped is itself capable of serving as a lubricant, then oil seal ring 180 may be omitted.

The housing, generally indicated by the reference numeral 157, is comprised of ring extension 165 of the stationary scroll member, flange 166, main housing section 181 which is flanged at 187 and is integral with a lower oil sump housing 183. The housing is attached and sealed to the scroll members through flanges 166 and 182 by a plurality of bolts 184 using an o-ring seal 185.

In operation, the two scroll members must be maintained in a fixed angular relationship, and this is done through the use of coupling member 154. The coupling member illustrated in the apparatus embodiment of Fig. 61 is essentially the same as the coupling member described in United States Patent 3,994,633 (see Fig. 14 of that patent and the detailed description thereof). Thus as seen in Fig. 61, the coupling member comprises a ring 190 having oppositely disposed keys 191 on one side thereof slidingly engaging keyways 192 in the inner surface of housing flange 182. A second pair of keys (not shown) are oppositely disposed on the other side of coupling ring 68 to slidingly engage keyways (not shown) in plate 153 of the orbiting scroll member. Another embodiment of a suitable coupling member is described and claimed in U.K. Patent Application No. 38206/77 (Serial No. 1,558,137).

Orbiting scroll member 152 has a stub shaft 195 affixed to or integral with orbiting plate 153. The orbiting scroll member is driven by a motor (not shown) external of the housing and engageable with compressor shaft 196 extending into the housing through an oil seal 197 and terminating in a crank plate 198 which may be affixed to or integral with shaft 196. Shaft 196 is mounted in the housing through shaft bearing 199 and crank bearing 200.

The driving means of the scroll apparatus is that described in U.K. Application No. 2687/78 (Serial No. 1,593,445) and is a fixed throw crank mechanism. The orbiting scroll member is affixed to drive shaft 196 through bearing mount 201, configured to have a counterweight 202 for the purpose of balancing the centrifugal force of the orbiting scroll member. Bearing mount 201 engages the stub shaft 195 through needle bearing 203 held in place by a snap ring (not shown). Interposed between bearing mount 201 and the outer surface of orbiting plate 153 of the

orbiting scroll member is a thrust face bearing 205 which acts as the axial force-applying means to urge the end plates and wrap ends of the two scroll members together to realize the desired degree of axial sealing. Thrust face bearing 205 carries the load from orbiting scroll member 152 through the crank bearing 200 and subsequently to the housing.

Main shaft 196, crank plate 198, bearing mount 201 and counterweight 202 make up an adjustable fixed-throw drive mechanism for the scroll pump of this invention. As noted above, the fact that in liquid pumps the liquid being handled has a greater viscosity than a gas in a compressor or expander and that the volume ratio maintained is one makes it possible to operate with a small clearance between the flanks of the scroll wraps. This makes it possible to use a fixed throw crank in driving the orbiting scroll member and to arrange a predetermined clearance between the flanks. Thus in affixing the orbiting scroll member to crank plate 198, provision is made to adjust the position of the wrap of the orbiting scroll member relative to the wrap of the stationary scroll member. This is accomplished by adjusting the position of the bearing mount 201/counterweight 202 assembly relative to crank plate 198 through the use of pivot pin 206 and locking screws 207 (preferably four) which extend through slots 208 in the bearing mount 201/counterweight 202 assembly into threading in crank plate 198. This mechanism is shown in detail in Fig. 7 of Application No. 2687/78 (Serial No. 1,593,445). In the embodiment described and shown in that Fig. 7, slots 208 are so configured as to permit the bearing mount 201/counterweight 202 assembly to be moved through a small arc prior to locking this assembly to crank plate 198 by means of screws 207.

Fig. 61 illustrates an adjustable fixed-throw crank; is also possible to use a fixed-throw crank which is not adjustable, that is one which is designed and constructed to have the bearing mount 201/counterweight 202 assembly initially and permanently affixed to crank plate 198 such that the desired clearance between the wraps of the orbiting and stationary scroll members is defined. In such an arrangement, the bearing mount 201/counterweight 202 assembly may be affixed to crank plate 198 through two or more screws as shown in Fig. 8 of Application No. 2687/78.

It has been found that by leaving a clearance between the wraps of the scroll members, wearing of the wraps may be substantially reduced or even eliminated and that special machining of the wraps is unnecessary. In operation, it is preferred that the clearance 100 between the flanks of the scroll member wraps be kept between about 0.001 and 0.005 inch. The clearance between the wraps may be established in one of several ways. In assembling the apparatus, a thin shim of metal of a thickness equivalent to the clearance may be inserted between the wraps and then subsequently removed when locking screws 207 are tightened. Alternatively, the orbit radius of the scroll members may be measured during a trial assembly and the orbit radius of the crank assembly set at this value minus the desired flank clearance. For any given liquid pump design and size, it will generally be convenient to operate the apparatus to determine what orbit is desired (equivalent to the distance between the machine axis 210 and orbiting scroll member axis 211); and then set bearing mount 201 at an orbit radius slightly less than that at which wrap-to-wrap line contacts occur.

The actual magnitude of the clearance finally left between the wraps is normally dependent, at least to some extent, on the size of the liquid pump and the viscosity of the liquid being pumped. In general, the larger the pump and the more viscous the liquid, the larger may be the clearance.

As noted above with regard to the general description of the apparatus illustrated in Fig. 61, there is provided an oil sump 158 in lower section 183 of the apparatus housing. The lubricating oil 212 from sump 158 is delivered to coupling member 154 and to the various shaft and drive bearings within housing 157 by means of one or more oil fingers 213 affixed to the coupling member. These oil fingers are of a length such that they are periodically dipped into oil 212 and then raised to fling the oil upward within the housing for circulation and return into the oil sump. An oil passage 214 is provided to conduct some of the oil flung directly into housing cavity 215, which surrounds the crank plate and bearing mount, to shaft bearing 199. In those cases where the pump is used to pump a liquid which in itself can serve as a lubricant and the oil seal ring 180 is not included, it is not necessary to have oil fingers 213 since the entire housing will normally contain liquid throughout substantially its entire volume.

Under some conditions of operation, e.g., pumping a liquid at an elevated temperature, it may be desirable to provide means to air cool the compressor housing, and through the housing to cool the elements of the pump and the circulating lubricating oil. Such means are illustrated in Fig. 61. An air duct 216, terminating in a duct cover 217, is mounted around the apparatus housing and supported on the drive end of a plurality of housing fin members 218. Cooling air is circulated through the air duct 216 by means of fan 159 which comprises a plurality of fan blades 219 mounted between the outer, belt-engaging rim 220 and the inner shaft engaging ring 221 of a pulley 222. Pulley 222 is affixed to main shaft 196 through a key 223 engageable with keyway 224 in shaft 196. Duct cover 217 is affixed to the scroll member end of the housing fin members 228, and it terminates short

of covering the scroll member end in order to leave a series of air discharge openings 225 so that air drawn in by fan 159 is circulated over the apparatus housing from drive end to scroll member end and discharged through openings 225.

A liquid pump was constructed as shown in Fig. 61 having the stationary and orbiting scroll elements of Figs. 1—4. Sealing ring 180, oil fingers 213 and housing cooling means were omitted. This pump was operated at 900 rpm and was found to pump SAE 20 hydraulic oil with an efficiency approximately equal to that of a gear pump of about the same capacity. The pump ran quietly and was free of pressure pulsations.

For some pumping operations it is desirable that the pump performing the pumping be immersed in the liquid being pumped. Although there has not, heretofore, been any great demand for such pumps, there has recently arisen a real need for a small pump which can be located within the fuel tank of an automobile or other self-propelled vehicle using a relatively light cut of fuel. To be effective, such a pump must be totally immersible in the fuel, e.g., gasoline or diesel fuel, being pumped. The recently developed need for a pump of this character is brought about through the requirement for installation of emission control devices, the use of which leads to the development of higher temperatures under the hood where fuel pumps have previously been located. These higher temperatures cause vapor locking of the fuel pump, a problem which is most readily solved by placing the fuel pump in the fuel tank to isolate it from excessive temperature, and connecting the fuel pump to the engine through a pressurized fuel line.

Since the use of a pump located in the fuel tank of an automobile places about as stringent requirements on a liquid-immersible pump as any conceivable use, the following detailed description of the pump of this invention will be presented in terms of its use for that application. It will, however, be appreciated that the pump of this invention may be used with liquids other than fuel oil, may be operated in an environment other than the liquid being pumped, and may be of any convenient size, e.g., much larger than that which meets the rigid size restrictions placed on it by its location within an automobile fuel tank, for example.

Moreover, the development of electronically controlled fuel metering systems intended to enhance engine operating efficiency has imposed additional demands on the fuel pump. Such systems require high fuel delivery pressures which cannot conveniently be produced by a simple centrifugal pump—the type heretofore used for in-tank applications.

Among those requirements which a fuel tank pump must meet for use in a passenger automobile are the ability to operate reliably and efficiently without maintenance for extended periods of time, e.g., 2000 hours, to deliver 185 pounds or about 31 gallons (84 kilograms or about 120 liters) of fuel per hour at 12 psig, to operate with a 12-volt D.C. motor with maximum current of 6.3 amp, and to run dry in an empty tank for at least ten minutes. Moreover, it must be self-priming, must operate with minimum noise, vibration and output flow variation, must fit through an automobile fuel tank access opening which means its maximum diameter must be no greater than 1—7/8 inches (4.76 cm), and it must be low in cost to manufacture. It is immediately apparent that the commonly used types of pumps—centrifugal or conventional positive displacement pumps—probably would not be able to meet all of these requirements. It is therefore necessary to look to some other type of pump for this purpose. It has now been found that a scroll-type liquid pump can be used to meet all of the above-listed requirements and to provide, in addition, very important advantages.

One embodiment of the scroll liquid pump of this invention which is suitable for immersion in the fuel being pumped is illustrated in Fig. 62 in longitudinal cross section. The pump comprises a main housing 240, a liquid inlet means 241, liquid discharge means 242, scroll pumping means 243, coupling means 244, orbiting scroll driving means 245, motor means 246, and axial load carrying means 247. In the following detailed description of the immersible pump, it will be convenient to describe first the motor means and the liquid discharge means inasmuch as these components of the pump are of more-or-less conventional design. The motor means 246 is an electric motor comprising an armature 248 and stator magnets 249 positioned and held within the central housing section 250 between bearing housing 251 (described below) and skirt 252 of discharge end block 253. Armature 248 is mounted on drive shaft 254 as is also face commutator 255, which contacts carbon brushes 256 to which electrical contact is made through oppositely disposed screw terminals 257 extending externally of the pump housing (see also Fig. 63).

Liquid discharge means 242 comprises a discharge conduit 258 in end block 253 and it has a check valve 259 to prevent the reverse flow of liquid through the pump when the pump is not operational and during start up. Check valve 259 is shown in Fig. 62 to comprise a ball 260 seated on an elastomeric ring 261, supported on an annular ring support 262, and held under an axial force by spring 263 held within conduit 258 by means of a ported plate 264. Spring 263 is, of course, chosen to permit valve 259 to open under a predetermined liquid pressure, e.g., about one psig for a fuel pump in an automobile gasoline

tank. A pressure relief valve 265 is also provided. It is shown in Fig. 62 to be of a construction similar to discharge valve 259, comprising a ball 266, seating ring 267, ring support 268, spring 269 and ported spring retaining plate 270. Spring 269 will be of appropriate strength to maintain relief valve 265 closed until a predetermined maximum liquid pressure, e.g., about 12 psig, is reached within the housing. It is, of course, within the scope of this invention to use any suitably configured valve means for discharge and relief valves 259 and 265, those shown in Fig. 62 being illustrative only.

Drive shaft 254 terminates within a central well 271a in discharge end block 253 and is supported and aligned through shaft bearing 271. A primary counterweight 272 is mounted on shaft 254 to counteract the forces generated transverse to the pump axis because of the eccentricity of the orbiting components. It is therefore necessary to provide a secondary counterweight means to achieve full dynamic balance by canceling out the moment generated by primary counterweight 272. In the embodiment illustrated in Fig. 62 this secondary counterweight may be provided either by incorporating suitably positioned weights in face commutator 255 or by providing suitable weight distribution in armature 248.

Figs. 64 and 65 illustrate another embodiment of the discharge end block of the pump and of means to make electrical connections with the motor. The discharge end block 273 is of stepped configuration terminating internally within the pump in a skirted ring 274 sealed to central housing section 250 through a sealing ring 275. Ring 274 serves to hold magnets 249 within the pump. The carbon brushes 276, making contact with commutator 277, are held by oppositely disposed brush holder 278 which extend through discharge end block 273 for connection with terminals 279. Drive shaft 254 terminates in well 280 and is aligned and supported by bearing 281.

In the embodiment of Fig. 64, a separate secondary counterweight 282 is mounted on shaft 254. As will be seen in the top plan view of Fig. 65, a valve-controlled discharge conduit 283 and pressure relief valve 284, similar in construction to that described in conjunction with Figs. 62 and 63, are provided for the embodiment of Fig. 64.

The flow of liquid through the pump is shown by arrows in Fig. 62. Liquid enters inlet means 241, is pumped by the scroll pump 243 from scroll pump chamber 285 into motor chamber 286, defined within the volume of housing 240, to flow around the motor and out through valve 259. The liquid pumped thus serves as a lubricant and coolant for the pump components.

The scroll pump, the porting system, axial load carrying means, coupling means and drive mechanism for the scroll pump are illustrated in detail in Figs. 67—77 in which the same reference numerals are used to refer to the same elements.

As will be seen in Fig. 66, scroll pump 243 comprises a stationary scroll member 287 and orbiting scroll member 288. Stationary scroll member 287 is comprised of an end plate 289 and an involute wrap 290 integral with or mounted on a separate member on the inner or facing surface 291 of end plate 289 (see for example U.S. Patent 3,994,635). Uniformly spaced keyways 292 are cut in the periphery of end plate 289 to engage keys 293 (Fig. 66) affixed to the internal wall of bearing housing section 251 and to maintain the stationary scroll member fixed within the pump.

End plate 289 of the stationary scroll member serves as the inlet end of the pump housing and has a central boss 294 (Fig. 66) defining an inlet conduit 295 in liquid communication, through a central port 296 in end plate 289, with the central zone of the scroll pump. As will be seen in Fig. 67, the stationary scroll element 287 has inner recessed liquid transfer passage means 296 and outer recessed liquid transfer passage means 297 comparable in configuration and function to recessed passage means 124 and 125, respectively of Fig. 41. In this embodiment the central port and inner recessed liquid transfer passage means are one and the same. Alternatively, the central port in the orbiting scroll member 287 may be circular in configuration and the inner recessed liquid passage may be configured as shown in Fig. 42.

As will be seen in Fig. 67, the orbiting scroll member 288 has a configuration similar to that of the stationary scroll member 287. The orbiting scroll member 288 is formed of an end plate 298 and an involute wrap 299 affixed to or integral with the inner surface 300 of end plate 298. Wrap 299 has an outer flank surface 301, an inner flank surface 302 and an end surface 303. As will be seen from Fig. 67, the orbiting scroll element 288 has inner recessed liquid transfer passage means 304 and outer recessed liquid transfer passage means 305 comparable in configuration and function to recessed passage means 133 and 124 of Figs. 43 and 44.

The operation of the scroll pump of Fig. 62 is identical to that previously described and the driving of orbiting scroll member 288 defines the moving pockets 306, 307 and 308 (Fig. 66), the volumes of which and liquid communication between which change to effect the movement of the liquid through the pump. As will be seen in Fig. 66, the peripheral discharge zone 309 of the pump surrounds the scroll involute wraps and extends around the end plate of the orbiting scroll member.

Because liquids have much higher viscosities than gases and because the volume ratio

within the pump is one rather than greater than one, the need for efficient radial sealing across contacting surfaces 292 and 303 of the wraps from pocket to pocket is not particularly stringent. As will be detailed below in describing the operation of the pump, the back pressure of the liquid flowing through the pump is sufficient to provide the axial forces required to urge the wraps and end plates into contact. Moreover, the outward radial flow of liquid through the pump provides hydraulic pressures within the pump to urge the flanks of the wraps of the scroll members into sealing arrangement as they make moving line contacts. The attainment of pulsation-free operation of this immersible pump is achieved in the same manner as described in conjunction with the scroll elements of Fig. 41—60.

The driving means, axial compressive load carrying means and coupling means are illustrated in Figs. 66—68. In the embodiment shown in these figures, the axial compressive load carrying means comprises a ball thrust bearing generally indicated by the reference numeral 312 and formed of a plurality of ball bearings 313 retained in the desired spaced relationship by two parallel ball retaining rings 314 and 315 having a plurality of equally spaced holes 316 configured to seat the balls 313. Retaining rings 314 and 315 are held in spaced relation by contact with the surface of balls 313 to define therebetween a plurality of radial liquid passages 317 through which the liquid flows from the peripheral pump discharge zone 309 into the scroll pump chamber 285. The major load on the scroll members is the compressive load generated by the liquid discharge pressure, and it is carried by the ball thrust bearing 312 as the axial load carrying means. Wear of the scroll members is thus minimized, thus giving rise to long pump life. Because of the ability of the axial load carrying means to maintain wear on the scroll members at a minimum it is possible to operate the pump of this invention with a relatively high discharge pressure, a fact which in turn gives rise to the attainment of good scroll sealing with the high efficiency and hence minimal power consumption.

In operation, the two scroll members 287 and 288 must be maintained in a fixed angular relationship, and this is done through the use of the coupling member generally indicated in Fig. 66 by the numeral 244. The coupling member 244 illustrated in Figs. 66 and 68 is essentially the same as the coupling member described in United States Patent 3,994,633 (see Fig. 14 of that patent and the detailed description thereof). Thus as seen in Figs. 66 and 68, the coupling member comprises a ring 318 having oppositely disposed keys 319 on one side thereof slidingly engaging keyways 320 in the inner surface of annular section 321 of bearing housing 251. (It will be appreciated that the longitudinal cross section of Fig. 66 is cut through the angled plane 66—66 of Fig. 68, and thus only one of the two oppositely disposed keys 319 and keyways 320 are illustrated [cf. Fig. 62].). A second pair of keys 322 oriented by 90° from keys 319 are oppositely disposed on the other side of coupling ring 318 to slidingly engage keyways 323 in end plate 298 of the orbiting scroll member 288. The coupling member 244 so serves as a spring to provide initial axial preloading on the orbiting scroll member during startup of the pump.

As described below in conjunction with Figs. 72—77, it is possible to combine the functions of the axial load carrying means and the coupling means in one apparatus component.

The orbiting scroll member driving means are detailed in Figs. 66 and 68. As will be seen in Fig. 66, drive shaft 254 is supported in main shaft bearing 324 held in shaft bearing housing 325, which, in turn, is integral with outer main bearing housing 251 through outer annular ring section 321, inner bearing housing 326 and inner ring section 327. Drive shaft 254 terminates in a flat stub shaft 328 which engages a keyway 329 (Fig. 68) in orbiting scroll drive yoke 330. This arrangement permits the orbiting scroll to move outward, urged by centrifugal and hydraulic forces, until its involute wrap is in contact with the involute wrap of the stationary scroll member. In this position the center 331 of yoke 330 is spaced from the center 332 of drive shaft 254 by a distance equal to the orbit radius of the orbiting scroll member. Drive yoke 330 is mounted in scroll drive bearing 333 supported in scroll drive bearing support ring 334 which is integral with the outer surface 335 of orbiting scroll member 288.

This scroll driving means provides an all-metal path (drive yoke 330, stub shaft 328 and drive shaft 254) for conducting heat away from the scroll drive bearing 330 during those periods when the pump in running dry, i.e., when the liquid in which it is normally immersed has been pumped out. The driving means is also designed to minimize friction losses through the placement of the bearings which minimizes the overturning moment on the orbiting scroll member and the loads on the motor bearings. This arrangement enhances pump efficiency and pump life as well as its dry running capability.

As will be seen in Figs. 66 and 68, outer annular bearing housing ring 321 has a number of equally spaced liquid ports 336 permitting the liquid to flow from peripheral discharge zone 309 through scroll pump chamber 285 into motor chamber 286.

Figs. 69—72, which are partial longitudinal cross sections of the inlet/scroll pump end of the pump, illustrate three additional embodiments of the axial load carrying means in pumps incorporating separate coupling means. In the embodiment of Fig. 69, the scroll mem-

bers 287 and 288 themselves serve in the capacity of axial load carrying means with the contacting ends 337 and 303 of stationary scroll member and orbiting scroll member wraps 290 and 299, respectively, carrying the loads as they make contact with the facing surfaces of the end plates of the mating scroll members, i.e., surface 300 of orbiting end plate 298 and surface 291 of stationary end plate 289. The embodiment of Fig. 69 is generally better suited to those pumps requiring moderate discharge pressures.

The axial load carrying means illustrated in Fig. 70 comprises an annular thrust bearing 338 having a plurality of radial passages 339 cut therethrough. The planar surfaces 340 and 341 of thrust bearing 338 make contact with the facing surfaces 291 and 298 of the stationary and orbiting scroll members, thus transmitting the axial compressive load of the pressurized liquid in the pump to this thrust bearing which is preferably formed of a synthetic organic plastic, e.g., a polyimide, in those pumps in which the scroll members are also formed of a synthetic plastic.

The embodiment of Fig. 71 is a modification of the embodiment of Fig. 70 in that an annular thrust bearing is used, but is formed as an annular ring extension 342 integral with inner surface 291 of stationary scroll member 287. A number of spaced radial passage 343 are cut in ring extension 342 to provide the necessary liquid communication between discharge zone 309 and pump chamber 285 and the axial load is carried by planar surface 187 making contact with orbiting scroll end plate surface 300.

Figs. 72—74 illustrate a modification in which the axial load carrying means serves also as the coupling means. The load carrying means comprise a plurality of equally spaced spheres 345 confined to a circular movement within circular indentations 346 and 347 in end plate surfaces 291 and 300 of the stationary and orbiting scroll members, respectively. The spheres 345 are maintained in radially and circumferential alignment by a sphere retainer ring 348 having holes 349 drilled therethrough. Fig. 73 illustrates in somewhat diagrammatic fashion the relative position of indentations 346 and 347 for the scroll element for one point in the orbit cycle. It will be seen from this figure that the centers of indentations 346 and 347 of the stationary and orbiting scroll members are located on circles having the same radius and are in axial alignment at that point of the cycle when the tangent lines of the two scroll members are all parallel.

The size of the indentations 346 and 347 relative to the diameter, D_s, of a sphere and the orbit radius, R_o, of the orbiting scroll member is shown diagrammatically in Fig. 74. In its movement during an orbiting cycle a sphere 345 must be able to travel a distance equal to one-half of the orbit radius, i.e., $R_o/2$, in all directions from its central position as shown in 74A. Thus it will be apparent that if the depth of an indentation 346 (or 347) were made equal to the sphere radius, R_s, the diameter, D_i, of the indentation must be $D_s + R_o$. Since, however, the depth of indentation 346 is less than R_s, it follows that D_i should be slightly less than $D_s + R_o$. Fig. 74A illustrates one cross sectional configuration of the indentations and Fig. 74B a top plan view. It is also, however, within the scope of this invention to cut the indentation with the proper diameter as a straight-sided well with a chamfered edge.

Fig. 74C is an enlarged cross section of the indentations and retainer ring showing the manner in which the orbiting scroll member end plate 298 (and its attached involute wrap) is free to orbit within the stationary scroll member while being maintained in the desired angular relationship with respect to the stationary scroll member. The spheres 346 serve the same role as the multiball thrust bearing of Fig. 66 in carrying the compressive axial load on the scroll members and therefore the pump embodiment of Figs. 72—74 exhibits the same advantageous performance characteristics as the embodiment of Fig. 66. In the absence of a separate coupling member, a spring washer 350 is provided between drive yoke 330 and the shoulder of shaft 254 to provide an axial preload on the scrolls during startup.

Figs. 75—77 illustrate a modification in which the coupling means serves also in the capacity of a load carrying means. The coupling means, generally designated by the reference numeral 351, is placed between the end plates 289 and 298 of the stationary and orbiting scroll members. The coupling member is an annular ring 352 cut to have two oppositely disposed keys 353 for slidingly engaging keyways 354 cut in surface 300 of orbiting end plate 298 and two oppositely disposed keys 355, at right angles from keys 353, for slidingly engaging keyways 356 cut in surface 291 of stationary end plate 289. As will be seen in Figs. 76 and 77, the coupling member has a series of equally spaced bearing pads 357 having planar surfaces 358 and 359 which engage facing scroll end plate surfaces 291 and 298, thus serving as the axial compressive load carrying means. Finally, the coupling member is cut to provide a plurality of liquid passages 360; and, as in the case of the modification of Fig. 72, a spring washei 350 is provided to provide an axial preload during startup.

In the pump embodiment shown in Figs. 78—80 spherical members are used as both axial compressive load carrying means and as keys in the coupling means. The coupling member comprises an annular ring 361 configured with bearing pads 362 and liquid passages 363 as in the case of coupling ring

351 of Figs. 75—77. There are, however, no keys on the coupling ring. A channel 364 is cut into the surface 365 of each bearing pad 362 which faces surface 300 of orbiting end plate 298. Channels 366 are cut in end plate surface 300 to correspond in configuration and axis orientation to channels 364 in the bearing pads; and a load carrying sphere 367 (bearing member) is positioned to experience coupling movement within each pair of the facing channels 364 and 366, the combined depth of which is slightly less than the diameter of spheres 367. Channels 364 and 366 have rim-to-rim lengths equal to or less than D + R_o wherein D is the diameter of the spheres 367. In a similar manner, channels 368 and 369 (Figs. 79 and 80) are cut into surface 370 of bearing pads 362 and in the facing surface 291 of end plate 289 of the stationary scroll member, and spheres 371 are positioned to experience coupling movement within each of these pairs of channels. The longitudinal axes of channels 368 and 369 are rotated 90° from the axes of channels 364 and 366. Thus spheres 367 and 371 carry the axial compressive load on the scroll members and also, in their restrained movement along the axes of the paired channels in which they are located, they maintain the required angular relationship between the orbiting and stationary scroll members.

The axial load carrying/coupling means shown in Figs. 81—83 represent a modification of the means of Figs. 78—80, in that rollers replace the spheres as the load carrying/coupling members. The coupling member is of the same general configuration as in Figs. 78—80, being an annular ring 361 with bearing pads equally spaced therearound and liquid passages 363. The four bearing pads 372 which are spaced at 90° from each other have coupling means associated therewith; while the remaining bearing pads 373 serve only in an axial load-carrying capacity. The surfaces 374 of bearing pads 372, which face surface 300 of orbiting end plate 298, have channels 375 cut therein; and surface 300 likewise has four corresponding channels 376 cut in it, the two channels defining a closed track in which roller 377 can travel as shown by Fig. 83. The combined depth of channels 375 and 376 is slightly less than the diameter of roller 377, and the distance of roller travel is equivalent to the orbit radius (R_o). Bearing pads 372 also have channels 379 cut in surface 379 which faces surface 291 of end plate 289 of the stationary scroll member. Likewise surface 291 has four channels 380 corresponding to channels 378; and as shown in Figs. 81 and 83, the channels 378 and 380 are oriented in respect to channels 375 and 376 so that rollers 381 travelling in channels 378 and 380 have axes at 90° from the axes of rollers 377. As in the case of spheres 367 and 371 of Figs. 78 and 79, the rollers of the modification shown in Figs. 81 and 82 serve both axial load carrying and coupling functions.

The use of an embodiment of a pump constructed in accordance with the present invention is illustrated in Fig. 35. The pump is immersed in the liquid 382 to be pumped, contained within a tank 383, e.g., the fuel tank of an automobile; and a high-pressure liquid line 384, attached to the discharge means 12 of the pump, is led out through suitable porting 385 in tank 383 to be connected to the desired liquid receptor, e.g., the carburetor of the automobile. Likewise, shielded electrical lines 386, connected to the screw terminals 257 are brought through porting 385 for connection to a source of electrical energy. A filter 387 is attached to the inlet means 241 of the pump to filter out any debris which may be in the liquid or settled on the bottom of the tank.

The pumps constructed in accordance with this invention and described herein, are self-priming, and they are capable of operating dry for a relatively long period of time, e.g., ten minutes or longer, without loss of performance. These pumps operate with minimal noise, vibration and output flow variation, and they can ingest debris without permanent damage due to radial compliance of the drive system. The direction of liquid flow through the scroll members provides for self-actuating scroll sealing between the flanks of the scroll wraps; and for self-actuating radial scroll sealing. Thus in the pump described herein it is not necessary to provide additional radial sealing means or to provide means to counteract any of the centrifugal forces acting upon the orbiting scroll members.

The unique liquid flow pattern through the pump, as shown by the arrows in Fig. 62, provides complete self-lubrication for all of the pump components, and eliminates the need for all valving except for the simple one-way valve associated with the liquid discharge means and the pressure relief valve.

The pumps described herein are particularly suited for placement in a fuel tank of an automobile. This is best illustrated by the fact that they can be made small enough to fit through an automobile fuel tank access opening (1—7/8 inches (4.76 cm) maximum pump diameter) and to have a capacity to deliver at least 185 pounds (84 kilograms) of fuel per hour at 12 psig (844 grams per square centimeter). Moreover, the scroll pump components may be formed (e.g., molded) from a suitable wear-resistant synthetic organic plastic and the remaining pump components may be mass produced from compatible plastics or metals, thus making it possible to meet the low-cost requirement for such immersible fuel pumps.

WHAT WE CLAIM IS:—

1. Mating scroll members suitable for incorporation in an orbiting scroll-type liquid pump,

comprising in combination a stationary scroll member, which when *in situ* is motionless, having a central liquid port and comprising a stationary end plate, a stationary involute wrap of one and one-half involute turns affixed to one surface of said stationary end plate, and stationary liquid transfer passage means in the form of a recess cut in said one surface of said stationary end plate; and an orbiting scroll member, which when *in situ* is orbited with respect to said stationary scroll member by driving means, comprising an orbiting end plate, an orbiting involute wrap of one and one-half involute turns affixed to one surface of said orbiting end plate; and orbiting liquid transfer passage means in the form of a recess cut in said one surface of said orbiting end plate; said stationary and orbiting recessed liquid transfer passage means being located and configured to permit fluid flow therethrough substantially immediately after said orbiting involute wrap has reached that point in its orbiting cycle when the scroll members define three essentially sealed-off liquid pockets.

2. Mating scroll members in accordance with claim 1, wherein said stationary recessed liquid transfer passage means is defined along one principal boundary by a partial tracing of said orbiting involute wrap edge and said orbiting recessed liquid transfer passage means is defined along one principal boundary by a partial tracing of said stationary involute wrap edge.

3. Mating scroll members in accordance with claim 2 wherein said stationary and orbiting recessed liquid transfer passage means are located either within said stationary and orbiting involute wraps, respectively, and have as another principal boundary a straight line drawn through the centre of said stationary and orbiting end plates, respectively, and parallel to a line of contact as a tangent to the generating radius of said stationary and orbiting involute wraps, respectively; or outside said stationary and orbiting involute wraps, respectively, and have as another principal boundary a line following the same contour as said one principal boundary and spaced radially outward therefrom; or within and outside said stationary and orbiting involute wraps.

4. Mating scroll elements in accordance with claim 3 wherein the depth of said recessed liquid transfer passage means approximates the thickness of said involute wraps, said another principal boundary of said outer recessed transfer passage is spaced from said one principal boundary by a distance equal to about two wrap thicknesses and said outer recessed transfer passage extends through an are between 45 and 90 degrees.

5. An orbiting scroll-type positive displacement liquid pump, comprising in combination the mating scroll members defined in any of the above claims 1—4; axial force applying means arranged to urge said scroll members into axial contact; coupling means to maintain said scroll members in fixed angular relationship; liquid inlet means and liquid discharge means; and driving means for orbiting said orbiting scroll member whereby the side flanks along with said end plates of said end plates of said involute wraps define moving liquid pockets of variable volume, a peripheral volume around said pockets and a discharge zone.

6. A liquid pump in accordance with claim 5 wherein said liquid inlet means communicates either with said peripheral volume and said liquid discharge means communicates with the inner pocket of said liquid pockets which serves as said discharge zone, or with the inner pocket of said liquid pockets and said liquid discharge means communicates with said peripheral volume which serves as said discharge zone.

7. A liquid pump in accordance with claim 5 or claim 6 wherein said driving means is arranged to effect the orbiting of said orbiting scroll member such that a small clearance is maintained between the side flanks of said involute wraps thereby to essentially eliminate wear of said side flanks over extended periods of operation while retaining the essential integrity of said liquid pockets.

8. A liquid pump in accordance with claim 7 wherein said driving means comprise, in combination a drive shaft terminating in a crank plate and rotatable on a machine axis; a stub shaft extending from said orbiting scroll member, having bearing mount and counterweight means rigidly affixed thereto and rotatable on an axis parallel with and spaced from said machine axis by a distance equivalent to the orbit radius of said orbiting scroll member; and locking means to rigidly affix said bearing mount and counterweight means to said crank plate in a predetermined relation thereby to define said clearance.

9. A liquid pump in accordance with claim 8 wherein said axial force applying means comprises thrust bearing means acting between said bearing mount and counterweight means and said end plate of said orbiting scroll member.

10. A liquid pump in accordance with any one of claims 5 to 9, suitable for immersion in the liquid being pumped, including housing means defining a chamber containing said scroll members therein and having said liquid inlet means on one end thereof and said liquid discharge means on the other end thereof; said driving means further including motor means located within said chamber between said scroll members and said other end of said housing, whereby liquid pumped radially outward by said scroll members and through said pump flows around said driving means and maintain a predetermined hydraulic pressure within said chamber to provide said axial force applying means.

11. A liquid pump in accordance with claim 10 including pressure relief valve means, said liquid discharge means comprising a discharge conduit having associated therewith pressure-controlled one-way valve means arranged to permit liquid to be discharged from said chamber when liquid pressure within said pump reaches a predetermined level.

12. Aliquid pump in accordance with claim 10 or claim 11 including axial compressive load carrying means.

13. A liquid pump in accordance with claim 12 wherein said coupling means and said axial compressive load carrying means comprise a single component serving as a coupling/load carrying means.

14. A liquid pump in accordance with claim 10 including additional axial force applying means for urging said orbiting scroll member into contact with said stationary scroll member during startup.

15. A liquid pump in accordance with any one of claims 10 to 14, including primary counterweight means to counteract forces generated transverse to the axis of said pump and secondary counterweight means to cancel out moments generated by said primary counterweight means.

16. A liquid pump in accordance with any one of claims 10 to 15 wherein said driving means comprises a drive shaft terminating in a stub shaft, an orbiting scroll member drive yoke being parallel and spaced apart when said pump is operating by a distance equal to the orbit radius of said orbiting scroll member.

17. A liquid pump in accordance with claim 16 wherein said stub shaft and said drive yoke are formed of metal and make metal-to-metal contact thereby to provide an effective heat transfer path for heat developed in said orbiting scroll member driving means, particularly when said pump is running dry.

18. Mating scroll members for use in an orbiting scroll-type liquid pump substantially as hereinbefore described with reference to either Figures 1 to 20 or Figures 21 to 40 of the accompanying drawings.

19. Mating scroll members for use in an orbiting scroll-type liquid pump substantially as hereinbefore described with reference to Figures 41 to 60 of the accompanying drawings.

20. An orbiting scroll-type liquid pump substantially as hereinbefore described with reference to Figure 61 or Figures 62 to 65 or Figures 66 to 68 of the accompanying drawings.

21. An orbiting scroll-type liquid pump substantially as hereinbefore described with reference to any one of Figures 69 to 71 of the accompanying drawings.

22. An orbiting scroll-type liquid pump substantially as hereinbefore described with reference to any one of Figures 72 to 83 of the accompanying drawings.

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Chartered Patent Agents.

Printed for Her Majesty's Stationery Office by the Courier Press, Leamington Spa, 1981.
Published by the Patent Office, 25 Southampton Buildings, London, WC2A 1AY, from which copies may be obtained.

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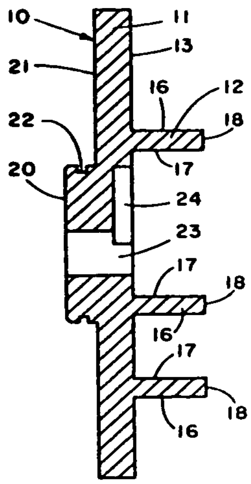
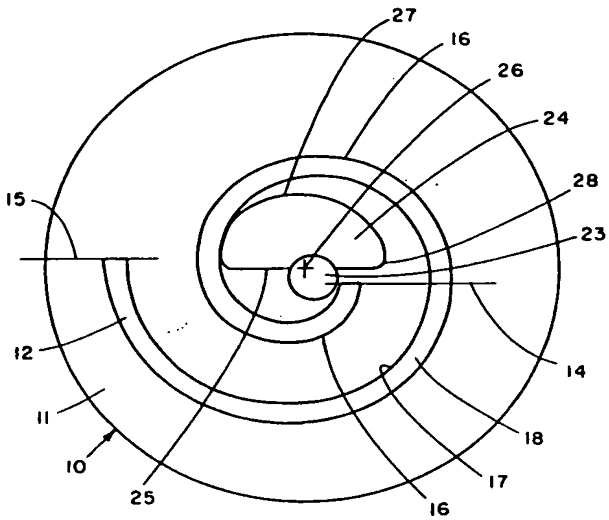


Fig. 2



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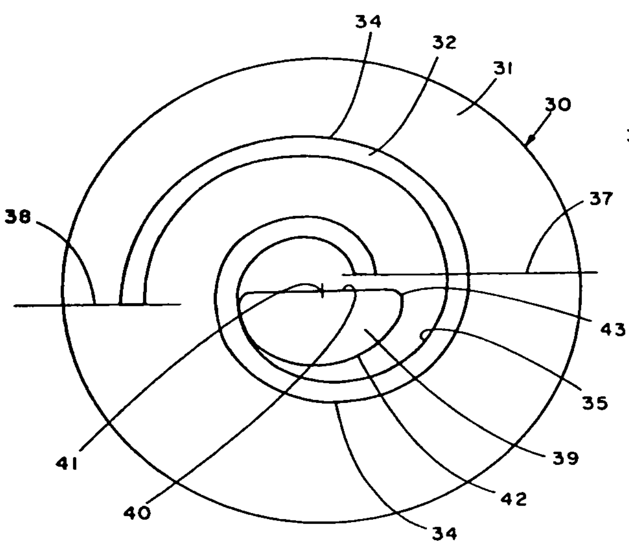

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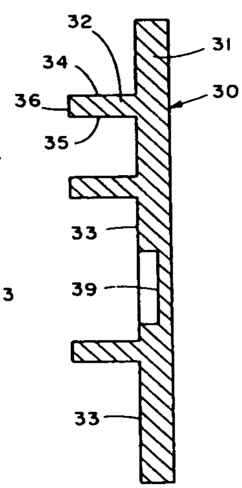

Fig. 4

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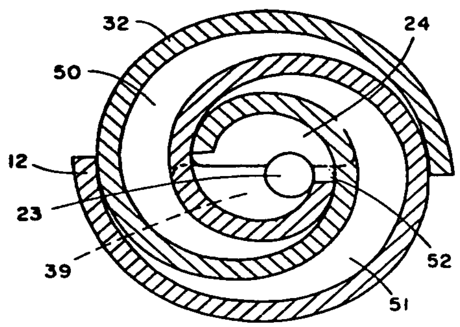

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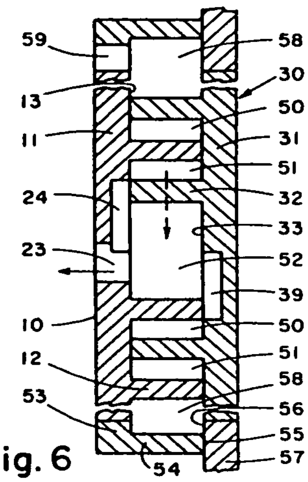

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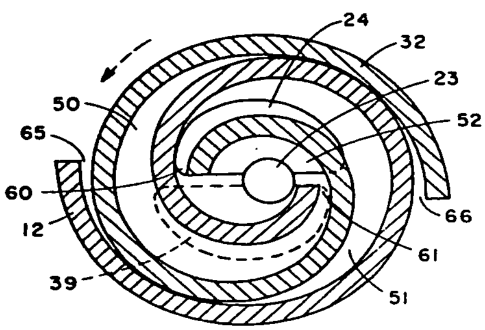

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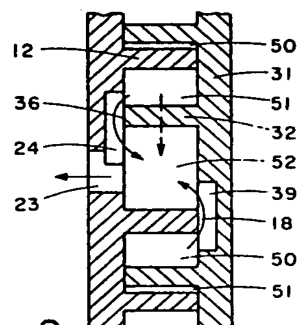

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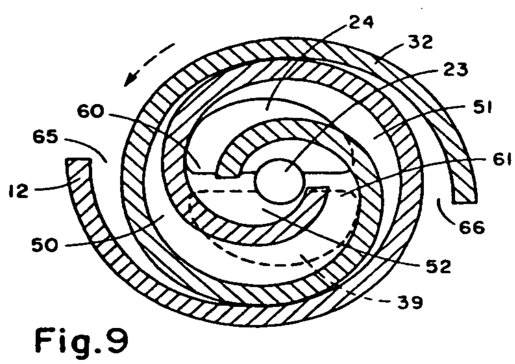

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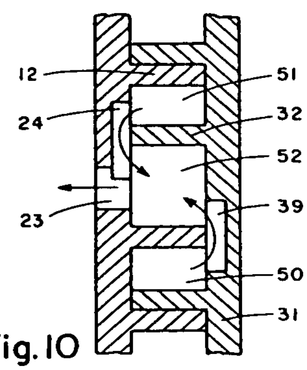

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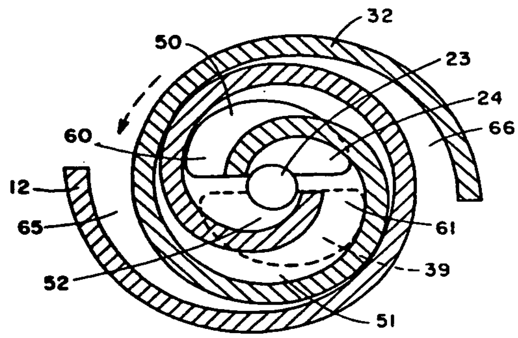

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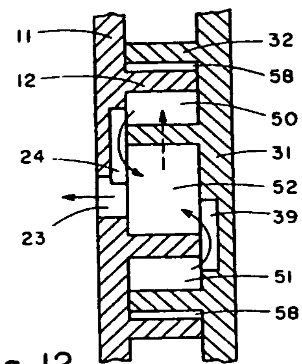

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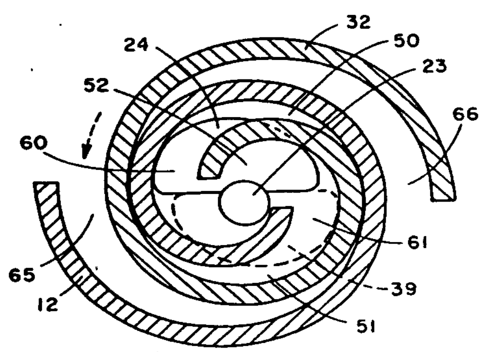

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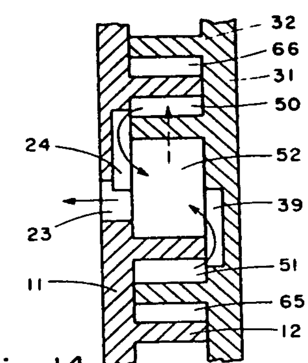

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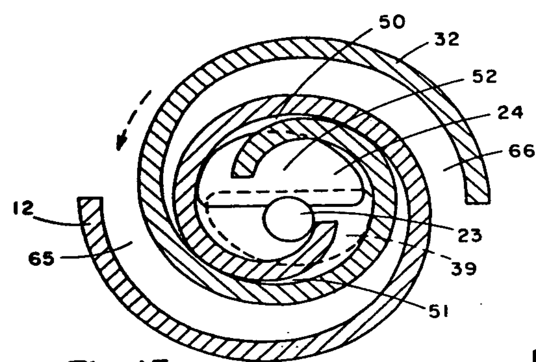

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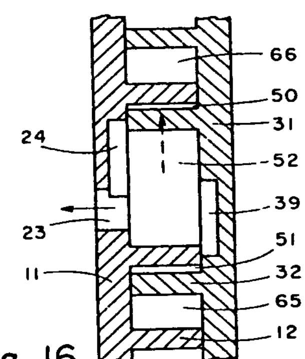

Fig. 16

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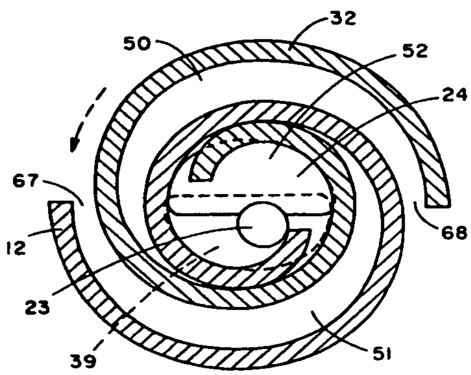

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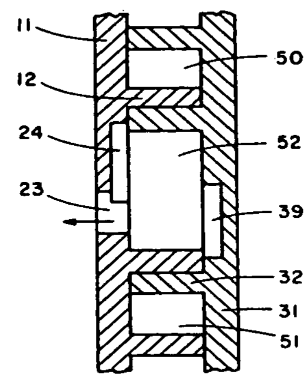

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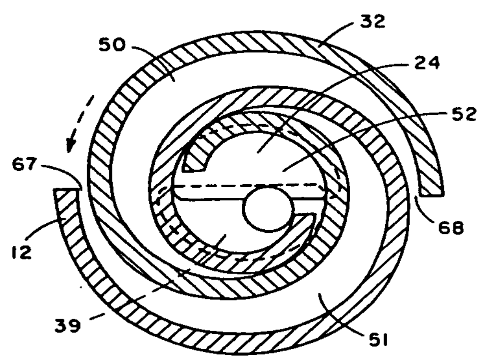

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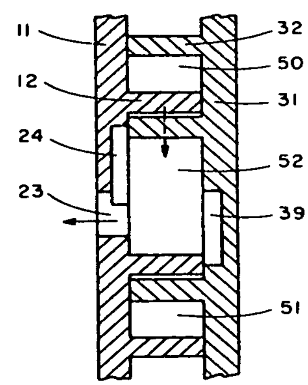

Fig. 20

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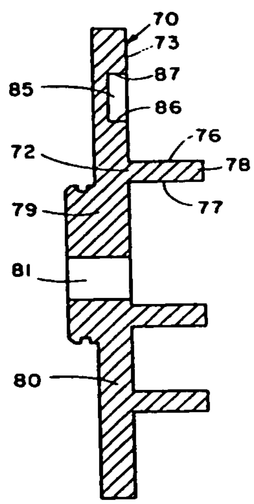

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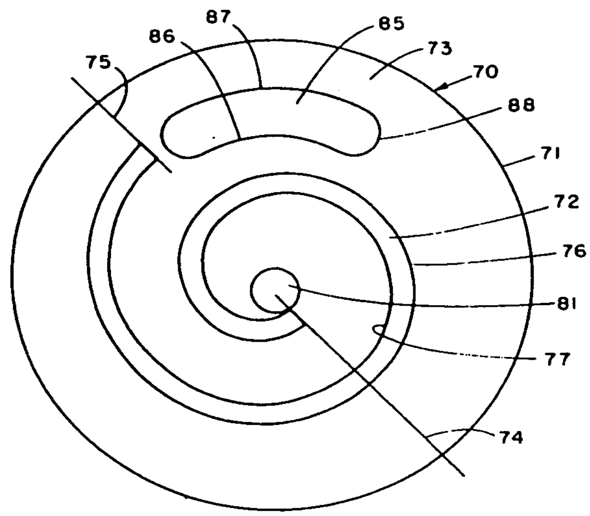

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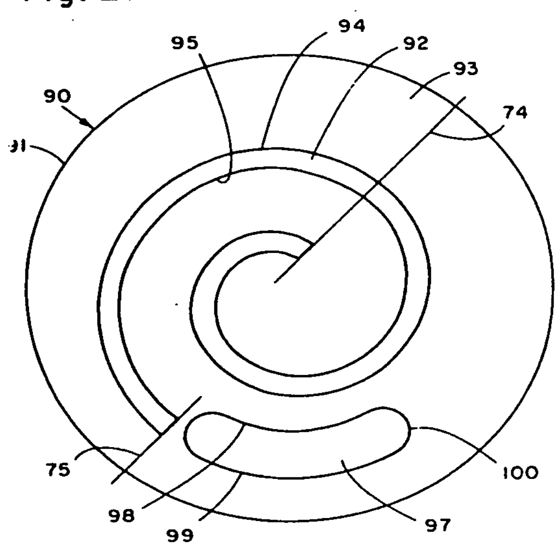

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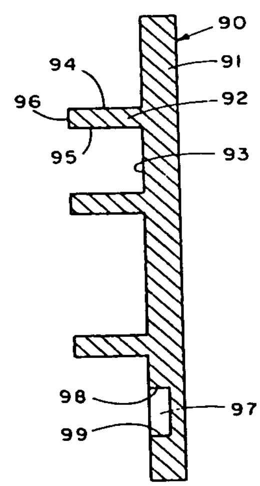

Fig. 24

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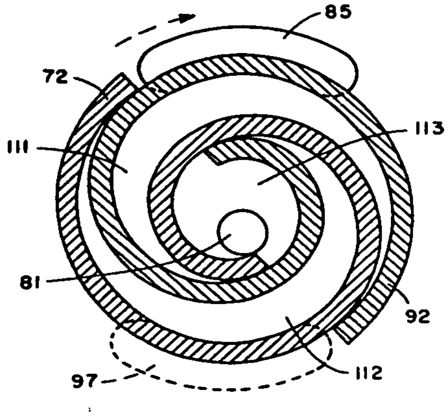

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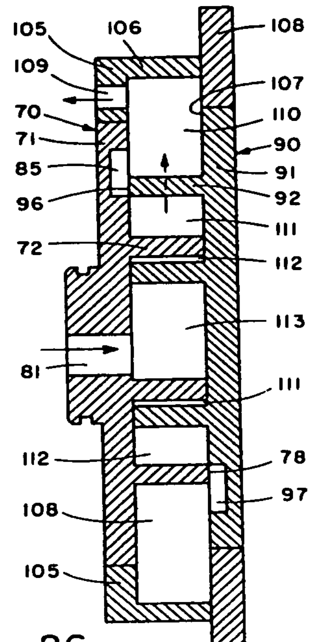

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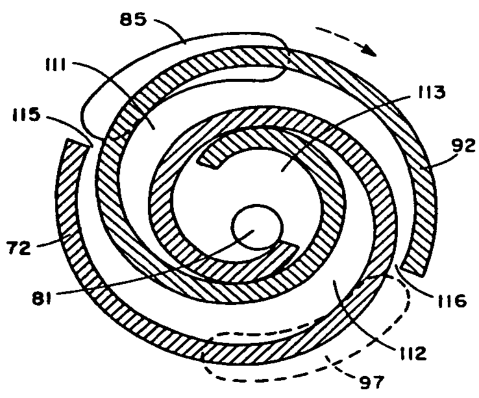

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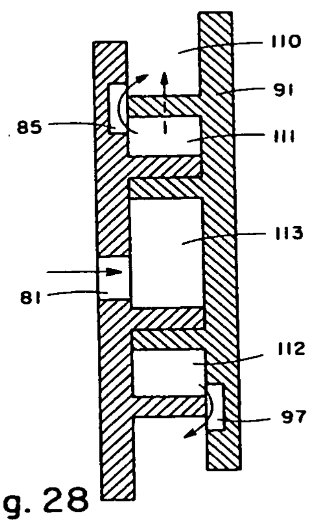

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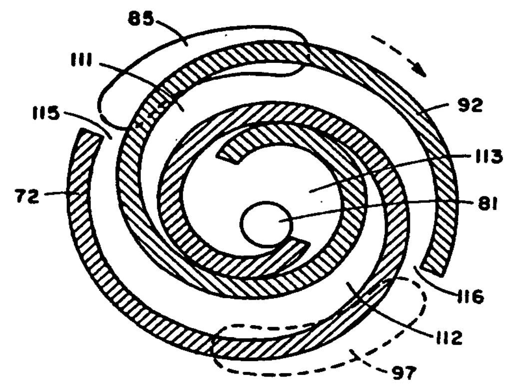

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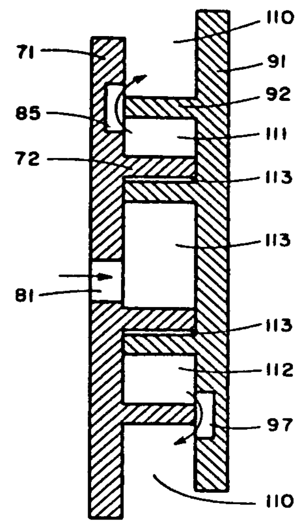

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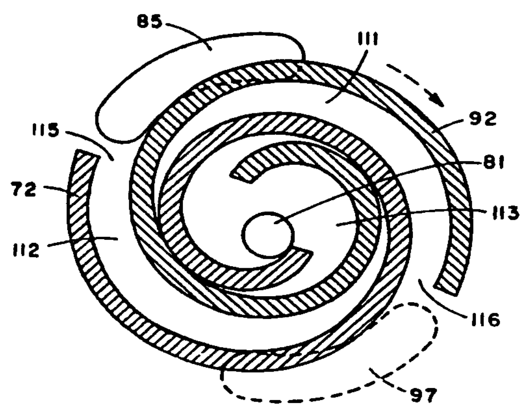

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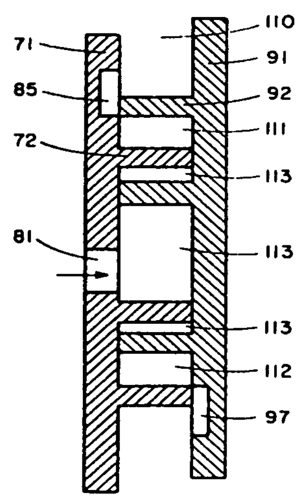

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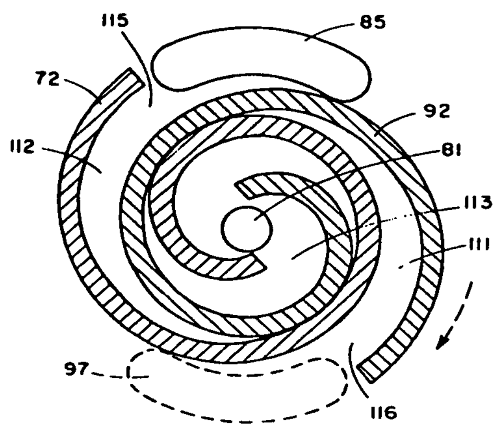

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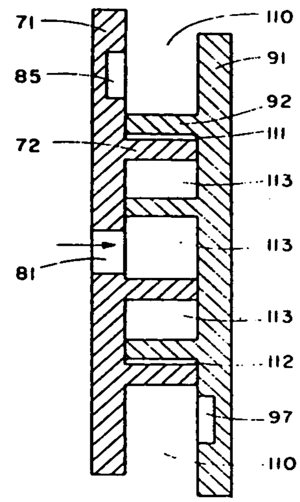

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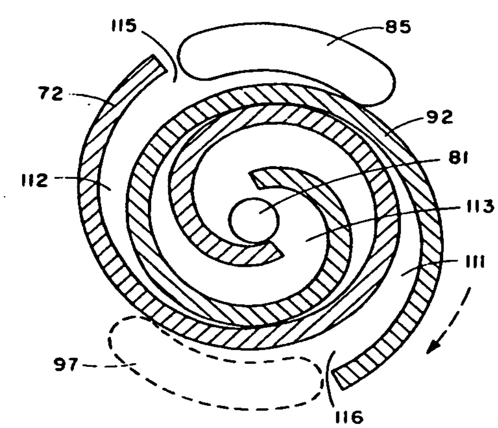

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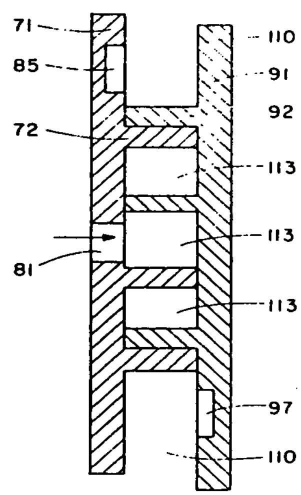

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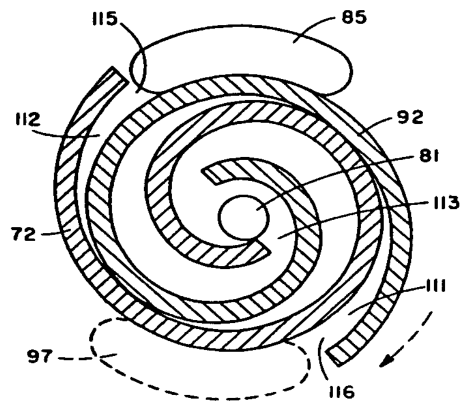

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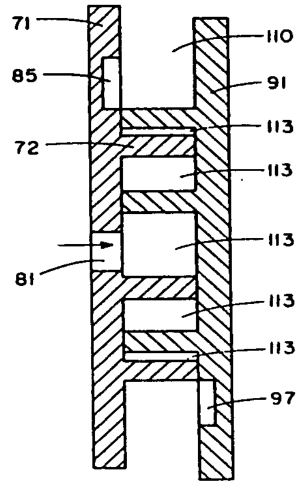

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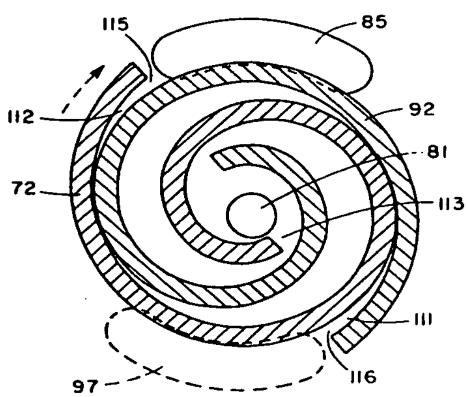

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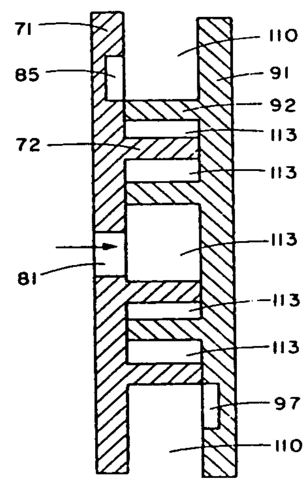

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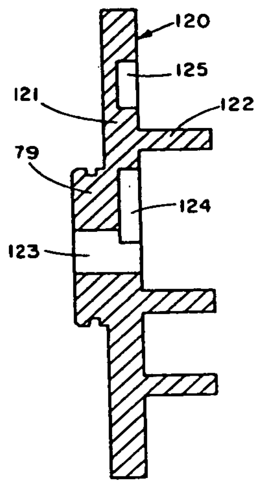

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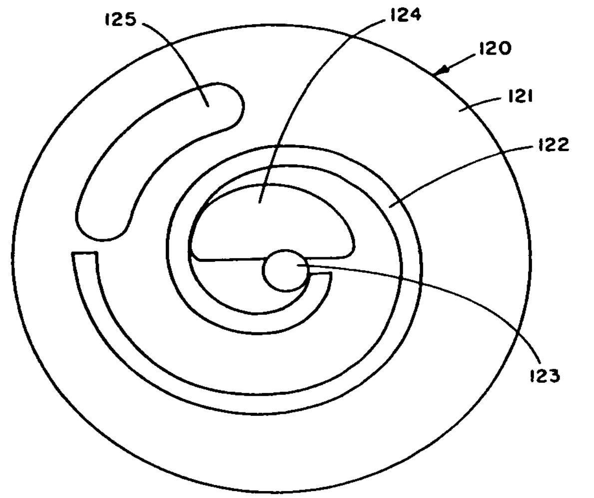

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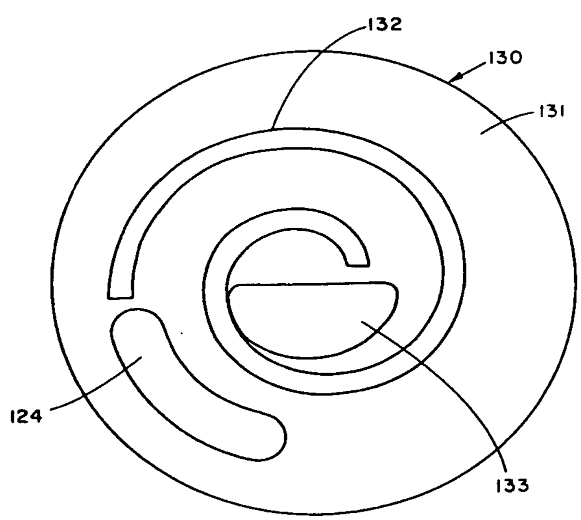

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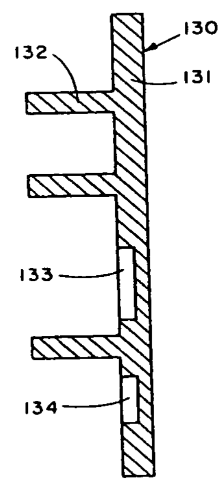

Fig. 44

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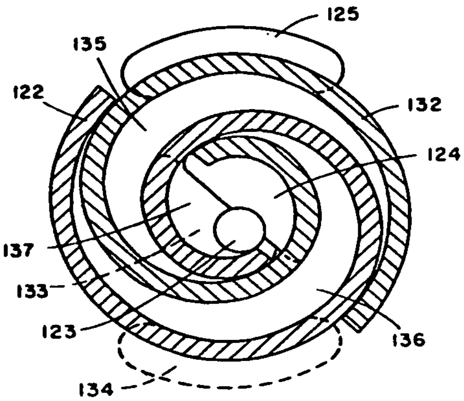
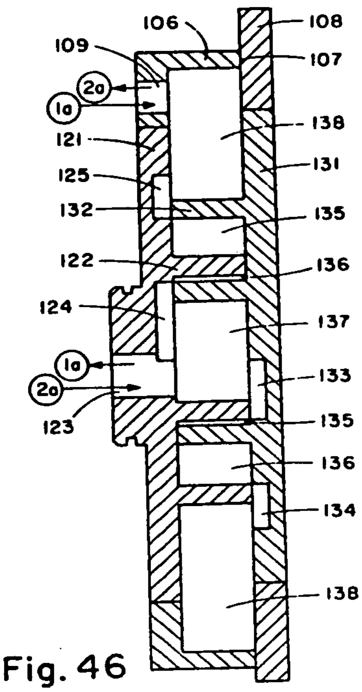


Fig. 45



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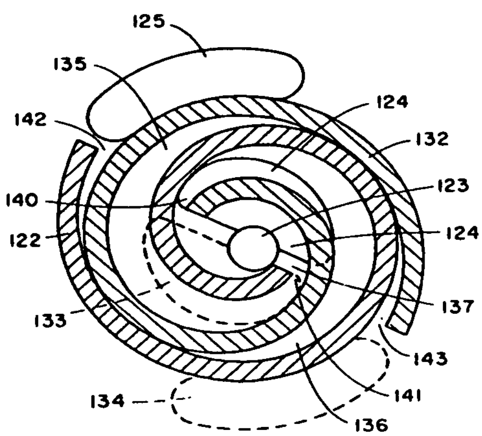

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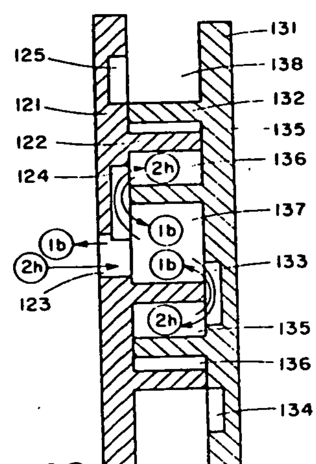

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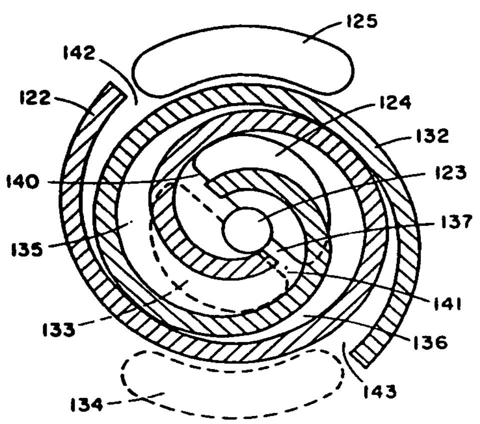

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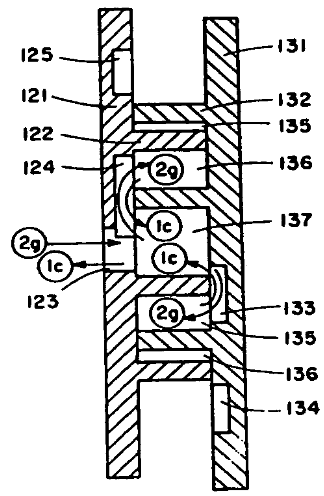

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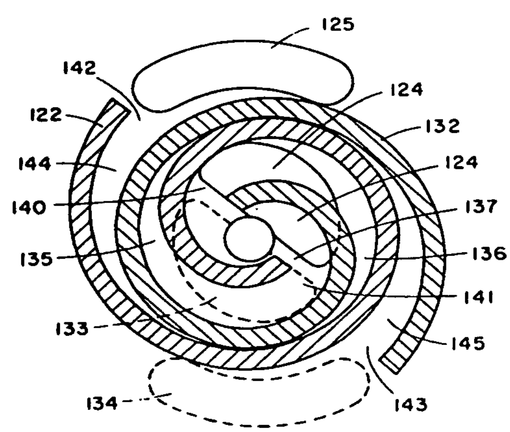

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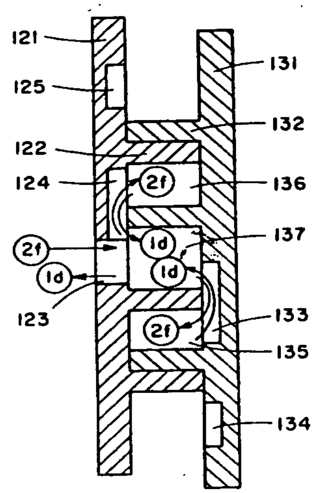

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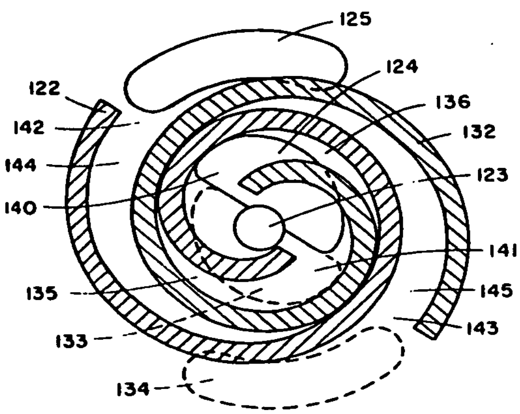

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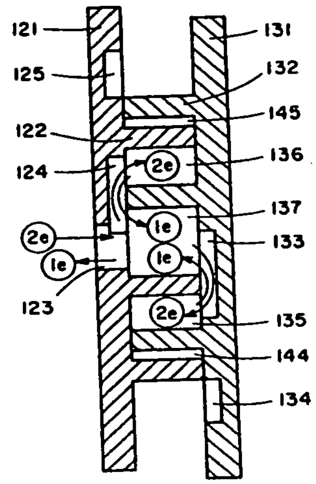

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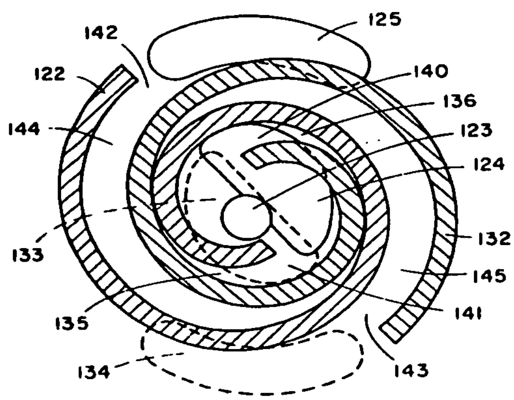

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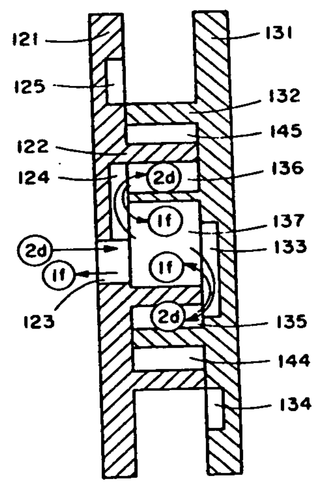

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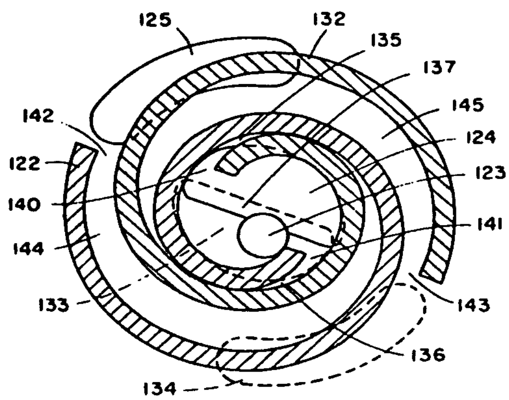

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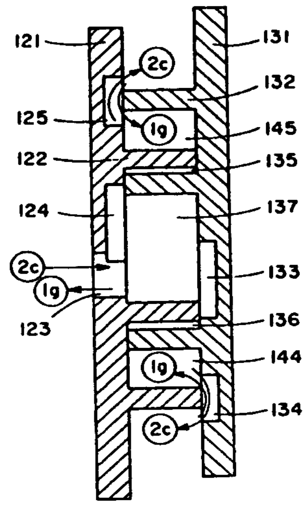

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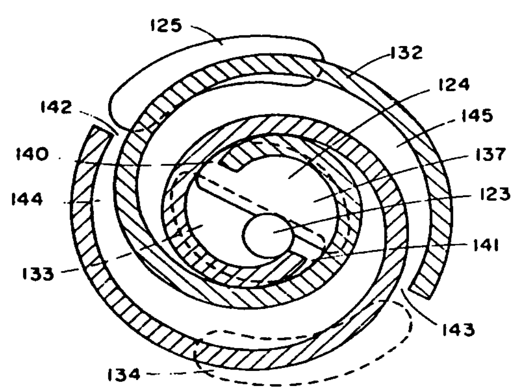

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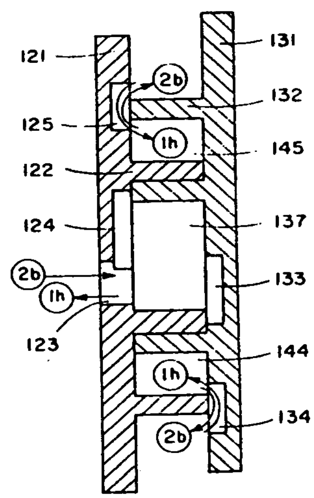

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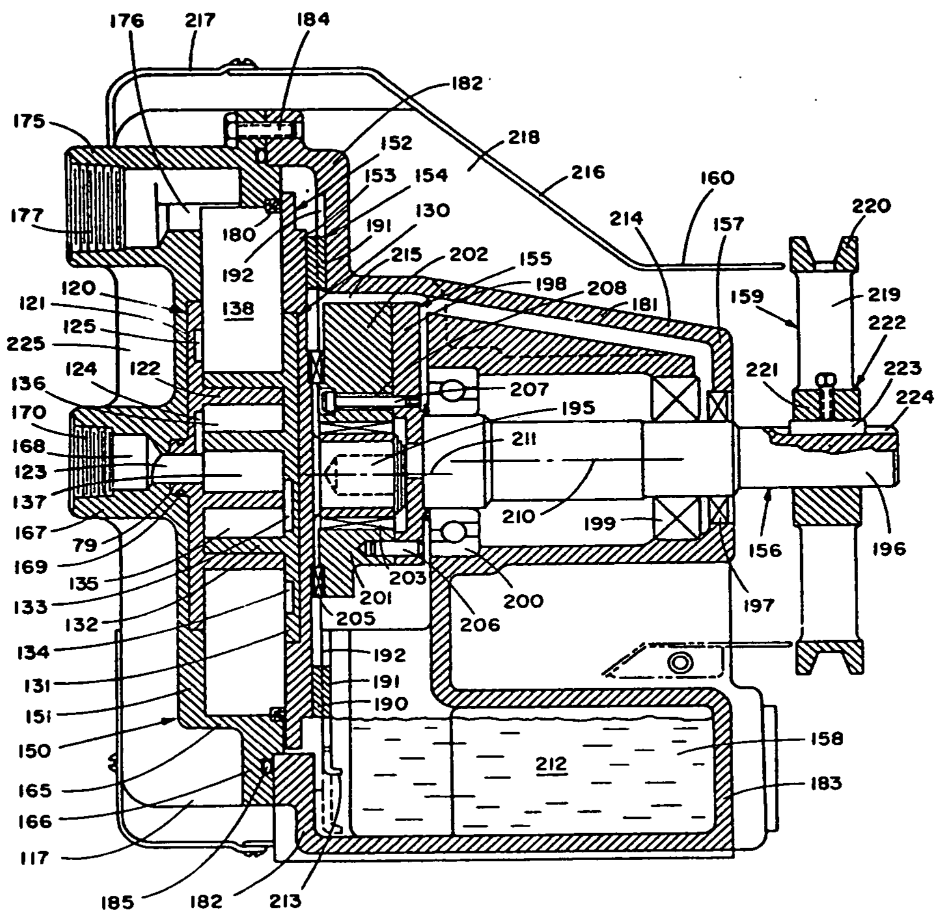
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Fig. 61

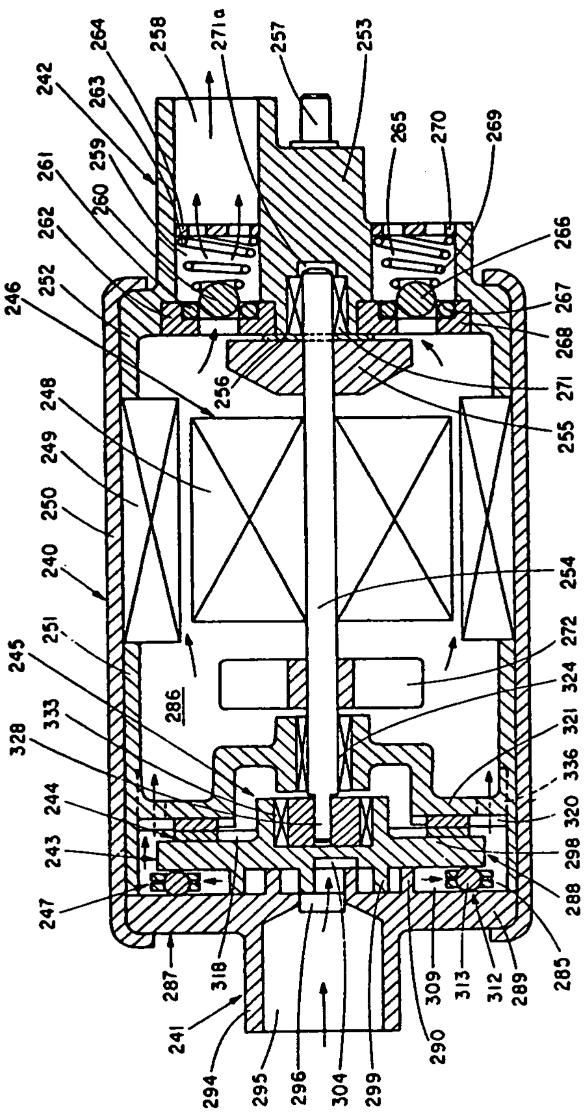
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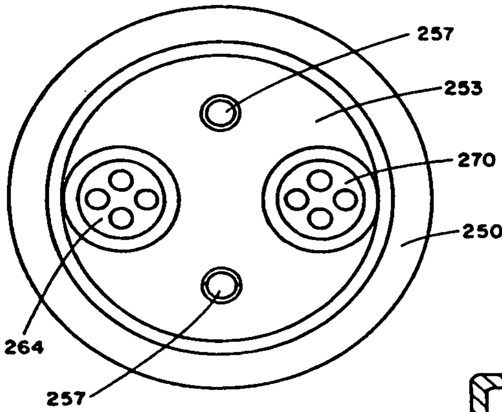
Fig. 62



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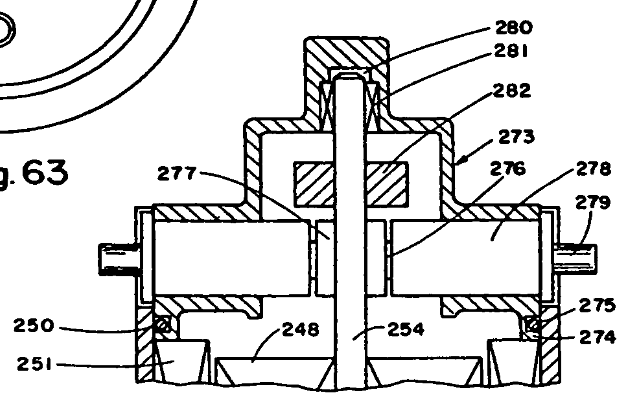

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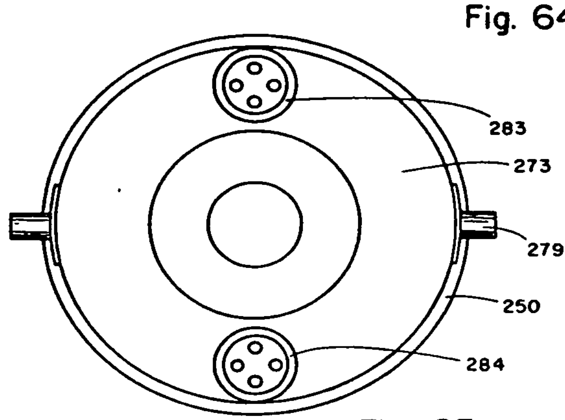

Fig. 65

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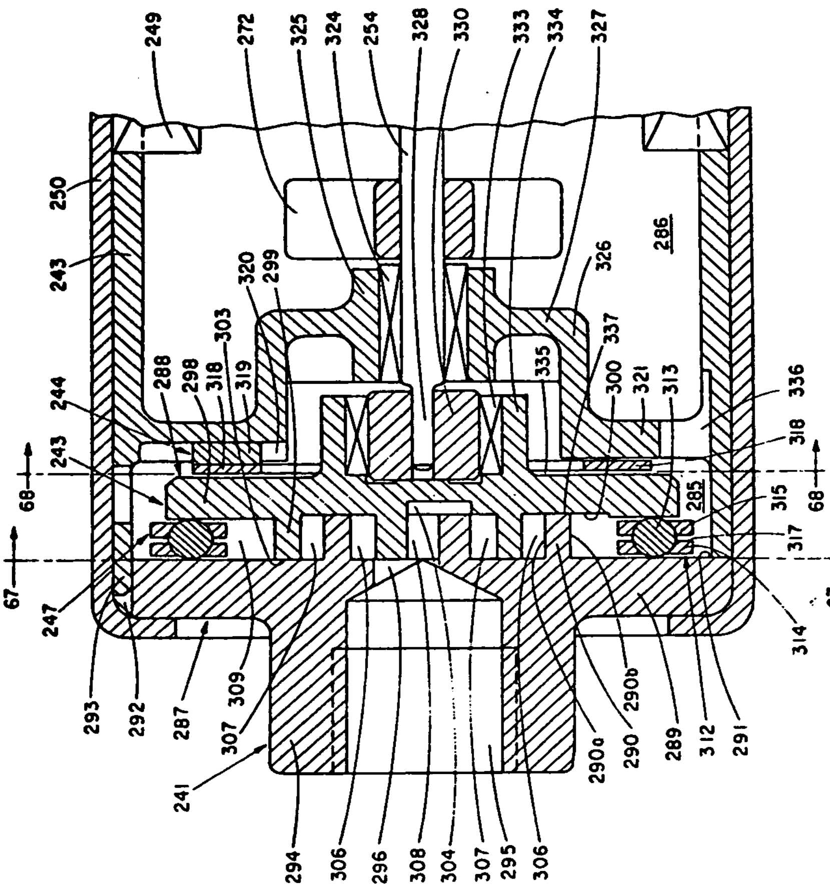

Fig. 66

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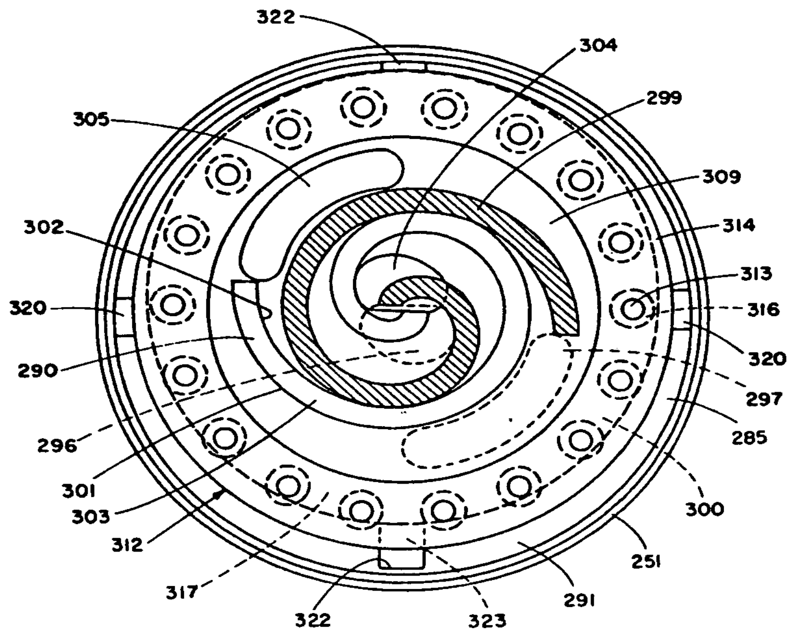

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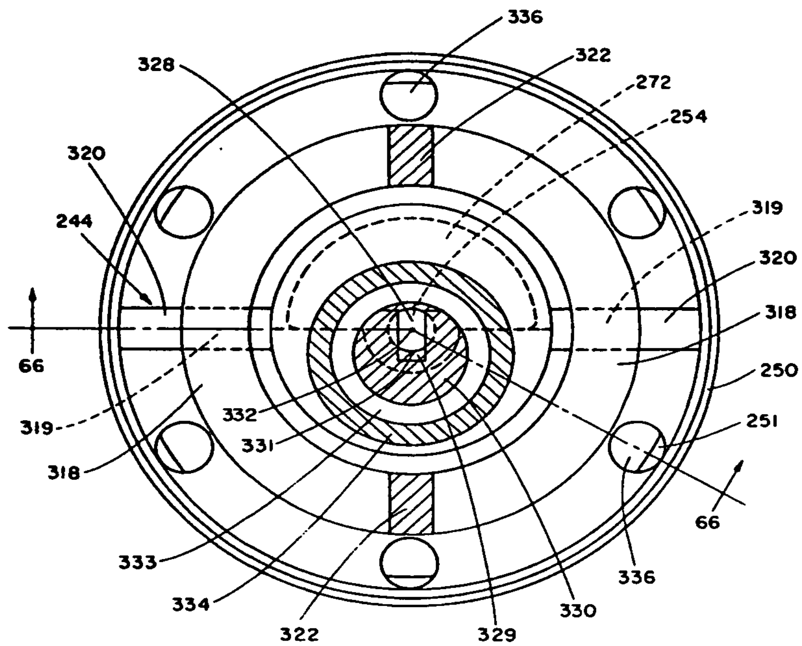
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Fig. 68

1593446 COMPLETE SPECIFICATION

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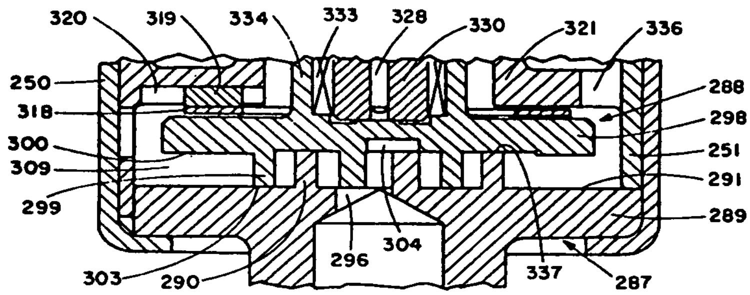

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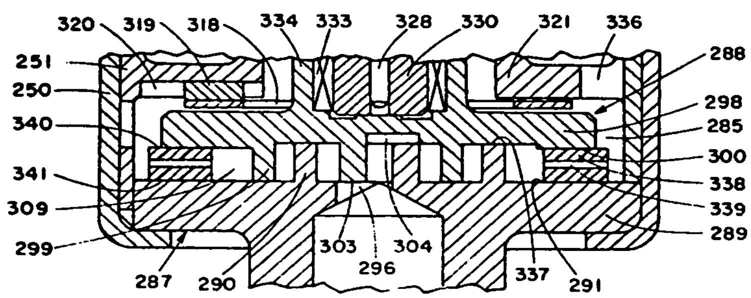

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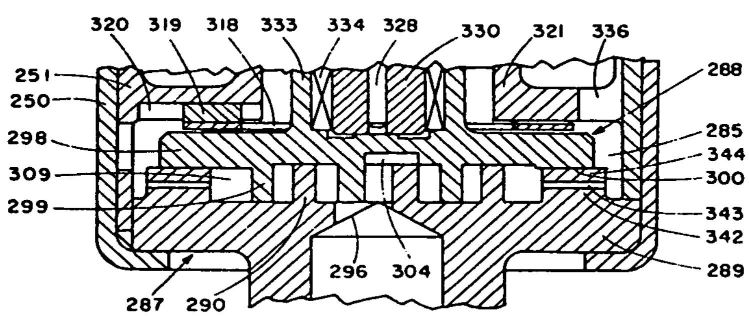

Fig. 71

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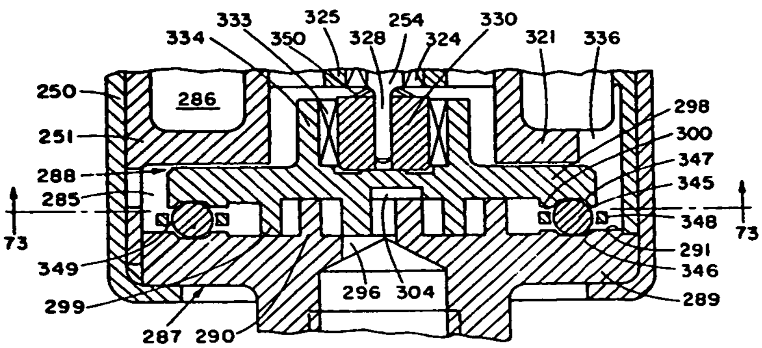

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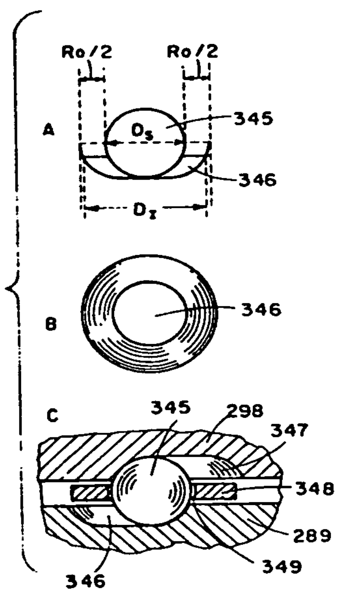

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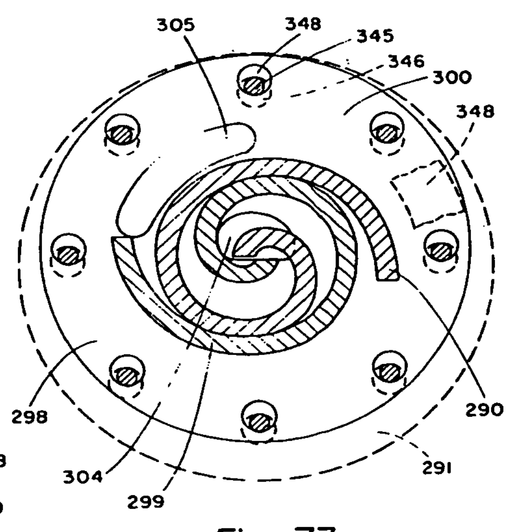

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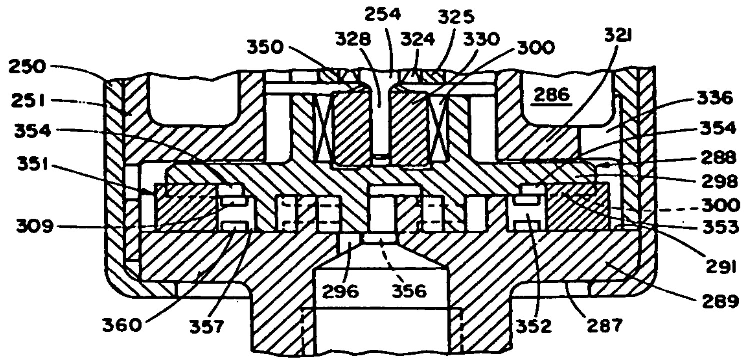

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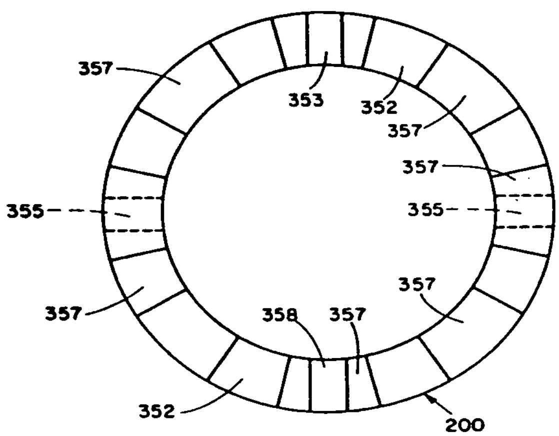

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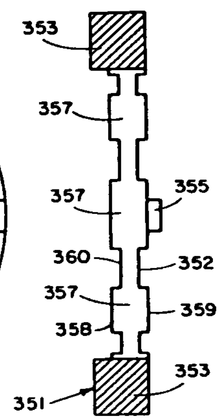

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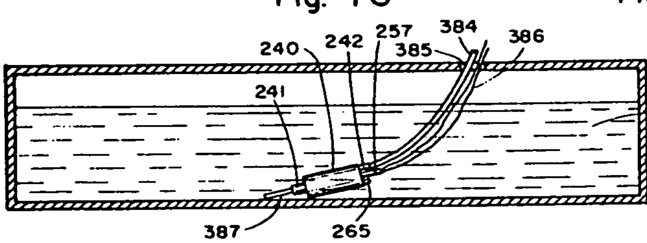

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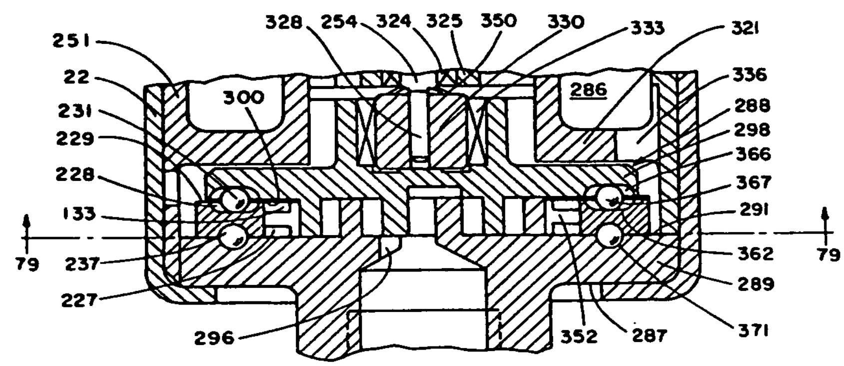

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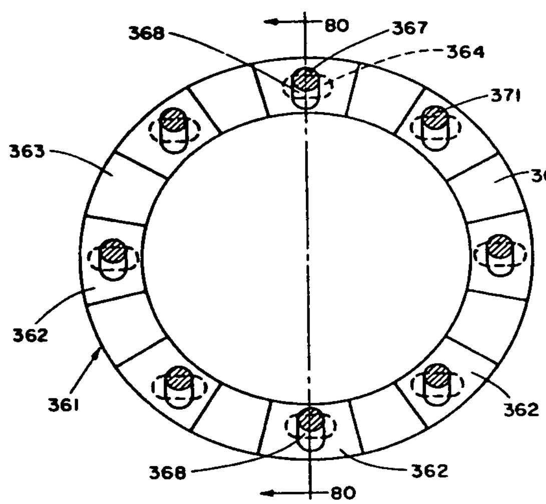

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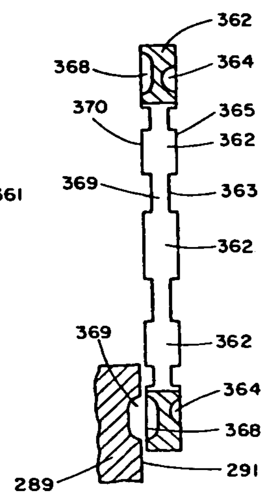

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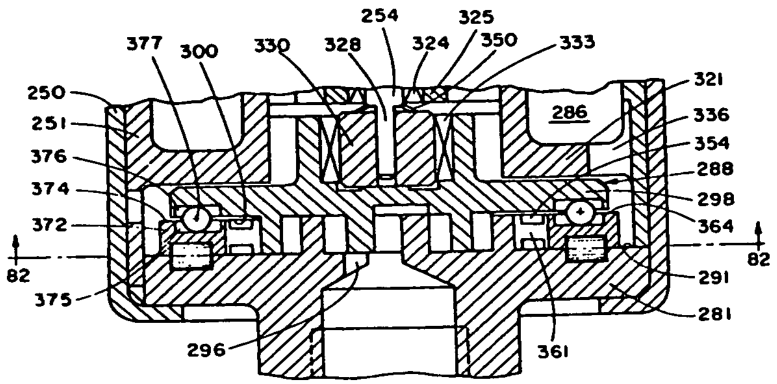

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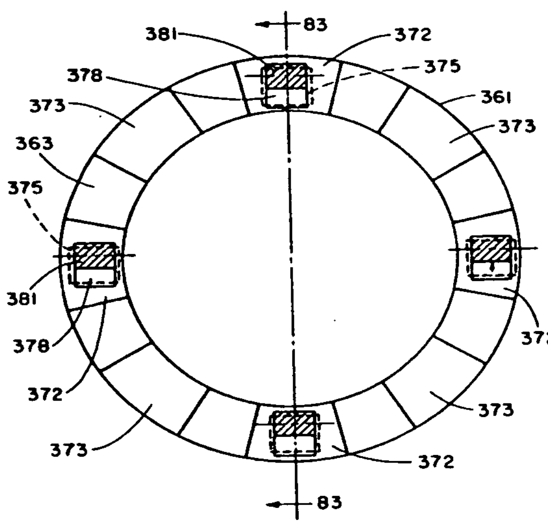

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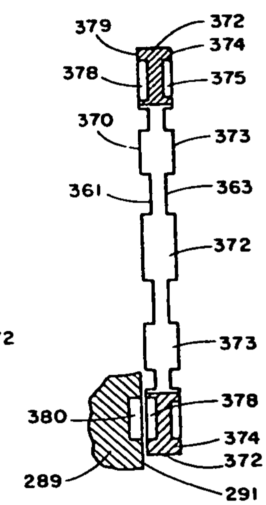

Fig. 83